EVALUATING FUEL BRIQUETTE TECHNOLOGIES AND THEIR IMPLICATIONS ON GREENHOUSE GASES AND LIVELIHOODS IN KENYA

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DECLARATION

This thesis is my original work and has not been presented for a degree in anyotheruniversity

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ACRONYMS

AWARD	African Women in Agricultural Research and Development
CFAs	Community Forest Associations
CO	Carbon monoxide
CO2e	Carbon dioxide equivalent
CO_2	Carbon dioxide
EF	Emission factors
FAO	Food and Agriculture Organization
GHG	Greenhouse gases
GWP	Global Warming Potential
HNP	Human Needs Project
IAC	Indoor air concentration
ICT	Information and communication technology
ICRAF	World Agroforestry Centre
ICRISAT	International Crop Research Institute in Semi-Arid Tropics
IDRC	International Development Research Centre
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
IR	Infrared
ITDG-EA	Intermediate Technology Development Group-East Africa
IUCN	International Union for Conservation of Nature
JICA	Japan International Cooperation Agency
JIRCAS	Japan International Centre for Agricultural Sciences
KCJ	Kenya Ceramic Jiko

KEFRI	Kenya Forestry Research Institution
Kg	Kilogram
Ksh	Kenya shillings
KPCU	Kenya Planters Cooperative Union
LEAP	Leadership enhancement in agriculture program
LPG	Liquid Petroleum Gas
MDG	Millennium Development Goal
MoPND	Ministry of Planning and National Development
PIC	Products of incomplete combustion
PISCES	Policy Innovation System for Clean Energy Security
$PM_{2.5}$	Fine particulate matter
RELMA	Regional Land Management Unit
SHG	Self- help group
SARDEP	Semi-Arid Rural Development Program
SNV	Netherlands Development Program
SSA	sub-Saharan Africa
US$	United States dollar

DEDICATION

In memory of my late father Njenga Waweru, who inspired me as I pursued my dream asa scientist since childhood but never lived to celebrate our achievement.

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ABSTRACT

Charcoal is theprincipal cooking fuel in Kenya which provides energy to 82% of urban and 34% of rural households. Poor households are opting to use unhealthy sources of fuel such as tyres, old shoes and plastics especially those in urban and peri-urban areas while many families are shifting from traditional meals that require long cooking times and are compromising dietary diversity and nutrition as a result. Faced with poverty and unemployment, communities are turning tofuel briquette which is made by compressing biomass material into a solid unit. Fuel briquette production methods in Nairobi and surroundings and their implications on the quality of the product were studied through focus group discussions with eight groups and one private company. The fuel briquette producing community SHG's in Nairobi comprised all those identified and locatedusing an existing database on self-help groups involved in waste management in Nairobi. One group SHG that produced sawdust fuel briquettes was identified in Naro Moro through PactKe an NGO working on Natural Resource Management in Laikipia county. Implications of fuel briquettes on the community livelihoods were also investigated. The results obtained were applied in designing experimentsto assess different fuel briquettes producing techniques using, (i) different binders namely soil, paper, cowdung and gum Arabica, (ii) pressing machines, (iii) charcoal dust from *Acacia mearnsii, Eucalyptus spp and Acacia xanthophloea,*(iv) sawdusts from *Grevillia robusta, Pinus patula*and*Cupressus lusitanica and (v)* carbonized sawdusts from the three tree species above in (iv).combustion characteristics which included calorific value, ash content and volatile matter of the fuel briquettes were conducted through Infrared (IR) spectroscopy and wet chemistry.In Near-infrared (NIR) and Mid-infrared (Mid-IR) the MPA Multi

Purpose FT-NIR Analyzerand Tensor 27–HTS-XTBruker FTIR equipments were used respectively. A double sampling approach was used whereby a spectral library of the total 40 samples for each type of fuel briquette and pure charcoal was first established and then a representative subset selected based on the chemical and physical spectral diversity in the library. These subset samples were analysed for ash content, calorific value and volatile matter using wet chemistry. Calorific value was measured using bomb calorimeterwhile volatile matter was measured using 0.5g of the sample which was heated in a furnace at 800 ^{o}C for five minutes. Volatile matter was then expressed as the percentage of loss of weight of the original sample. The ash content was determined the same way as volatile matter but this time the sample was heated for 1.5 to 2 hours.Carbon monoxide (CO) was measured at 10 seconds intervals using EL-USB-CO carbon monoxide data logger, DATAQ Instruments(603-746-5524). Fine particulate matter ($PM_{2.5}$) measurements were taken per minute using a particulate matter meter, UCB, Berkeley Air Monitoring Group. Carbon dioxide was measured at intervals of 5 minutes using Taile 7001 Carbon Dioxide and Temperature, LASCAR(603-746-5524).

Locally produced charcoal dust briquettes bonded with corn starch or paper had the highest calorific values of 23.6kJ/g and 21.4kJ/g respectively. While comparing with locally produced fuel briquettes, quality of charcoal dust bonded with paper and charcoal dust bonded with soil briquettes rose by 25% and 75% respectively. Contaminants comprising of chromium, mercury and lead were high in briquette made from organic waste as the feedstockin the informal settlements and dumpsites. Burning sawdust briquettes bonded with gum arabica emitted high levelsof $PM_{2.5}$. Carbonizing raw

sawdust for fuel briquette production increased calorific value by 40% and reduced indoor air concentration (IAC) of CO and $PM_{2.5}$ by 67% and 98% respectively.Type of tree species from which charcoal dust was sourced influenced combustion properties and IAC of $PM_{2.5}$ of fuel briquettes while type of sawdust influencedIAC of $PM_{2.5}$.Fuel briquettes made from charcoal dust bonded soil performed the best when both combustion and emission qualities were considered. Supplying energy and cooking a traditional meal with charcoal briquettes and charcoal accounts for 1.3 and 4.9-6.3 kg CO_2e. per meal respectively if forests are not regenerated. These amounts decline to 0.18 and 1.9 kg CO_2 eq. per meal for charcoal briquette and charcoal when carbon dioxide from carbonization and cooking stages is taken up by regrowing biomass.Adopting improved wood production and wood carbonization systems will result in additional cooking fuel supply and reduced GWP. It is critical for householdsto adopt technologies that increase fuel efficiency and reduce emissions from cooking with charcoalbriquettes and charcoal.There is need to improve the quality of fuel briquettes produced by community groups through trainings while scaling out of high quality fuel briquettes such as that made from charcoal dust bonded with soil is desirable.

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND INFORMATION

Woodfuels account for over 80% of primary energy supply, and more than 90% of the population rely on firewood and charcoal (IEA 2006), with the highest per capita woodfuel production – 0.69 m^3/year for Sub Saharan Africa (SSA) against 0.27m^3/year for world average in 2011. Due to the expected high rates of urbanization in SSA, the charcoal demand isprojected to double between 2000 to 2030(Arnold 2006).Charcoal is the principal fuel that provides energy for 82% of urban and 34% of rural households in Kenya (Karekezi, 2002; MoE, 2002).The poor populations, who are the majority users of wood charcoal, cannot afford to use electricity and/or liquid petroleum gas (LPG) for cooking because of the high costs of fuel and related cooking appliances (Mugo *et al.* 2007). It is predicted that in the coming decades woodfuels will remain dominant within the energy portfolio, especially for cooking, for the majority in SSA. Charcoal will be consumed by a wide range of socio-economic groups while firewood remains important for the poorest who cannot afford the former (Brew-Hammond& Kemausuor 2009; Mwampamba, et al.,2013). Under a business-as-usual trajectory, the trend can accelerate forest degradation with undermining effects of the ecosystem services, and increase greenhouse gas emissions, thus increase vulnerability of SSA countries to risks caused by climate change, whose signs are already observed in various parts of the continent (IPCC, 2007).

Combustion of biomass fuels emits pollutants that contribute to over 1.6 million annual deaths globally, of which 400 000 occur in (SSA) and women and children suffer most, thus often labeled as “killer in the kitchen” (Bailis and Kammen, 2005). If the patterns of energy use for household cooking do not change, it is estimated that diseases attributable to indoor air pollution will cause 9.8 million premature deaths by 2030 (Bailis, 2005). Carbon monoxide (CO) and particulate matter (PM) are the major pollutants released from incomplete combustion of solid fuels used by households (Doggalia et al., 2011). CO indirectly affects global warming through atmospheric photochemical reactions that in turn affect GHG levels. CO have higher global warming potential per kilogram of carbon, than CO_2 (Pennise et al., 2001). There is a need therefore to link knowledge on fuel briquette quality to indoor air pollution.

Due to the high costs of cooking fuel, poor households often use unhealthy materials such as old shoes, used plastic containers and old plastic basins (Gathui and Ngugi, 2010). Further poor households are opting to cook foods that take a short time to prepare irrespective of their nutritional value. Faced with poverty and unemployment, communities are turning to fuel briquette making through recovering charcoal dust, among other organic by-products. Fuel briquettes are used as a compliment or substitute to charcoal. Fuel briquettes are made by compressing biomass material such as charcoal dust, sawdust and other wood residues or agricultural by-products into a uniform solid unit (Sotannde *et al*. 2010a; Rousseta *et al*. 2011).Briquetting biomass is done using various techniques, either with or without binder. For charcoal and other biomass material that lacks plasticity, addition of a sticking or agglomerating material, preferably combustible is required to enable the formation of solid briquettes (Rousseta *et al*. 2011). Common binders include starch, gum arabica, soil, animal dung or waste paper. Biomass briquettes are mostly used for cooking, heating, barbequing and camping in countries such as the United States of America , Australia, Japan, Korea and Taiwan and countries in the Eureopean Union. In developing countries, biomass briquettes are mainly for domestic usage (Sotannde 2010b). In the Kenyan situation, like in many developing countries, briquette production is focused on providing good quality cooking fuel. It is therefore important to understand the effects of various types and amounts of raw material and binder on briquette quality.

Biomass residues generated by the wood-based industry in most developing countries have potential to alleviate cooking energy poverty as demonstrated in Cuba, Nigeria, Brazil, China, and Kenya (Suarez *et al*. 2000; Sotannde et al. 2010a; Rousseta *et al*. 2011; Gominho *et al*. 2012; Wamukonya and Jenkins, 1995).Agricultural by-products are used in briquette production such as rice straw and rice bran in China (Chou *et al*. 2009), maize cobs in Thailand (Wilaipon, 2007) and coffee husks in Brazil (Felfli, *et al*. 2010). Adoption of fuel briquette is spreading in Kenya’s urban and rural areas and the type of fuel briquettes produced depends on the locally available material. A study by Terra Nuova and Amref Kenya showed that sugarcane bagasse was used in Mumias, charcoal dust was used in Nairobi and other urban areas, coffee husks were used in Kiambu/Muranga, gum arabica was used in Isiolo, tree leaves were used in Machakos/Makueni, water hyacinth was used in Kisumu and rice husks were used in Mwea (Terra Nuova and AMREF-Kenya, 2007).To contribute to development of viable options for biomass cooking fuel in Kenya, there is need to evaluate local production of fuel briquette and the quality of the product and implication on emissions and climate change.

1.2 OBJECTIVES

Overall objective

To identify appropriate fuel briquetting technologies for sustainable environment and social-economic benefits.

The specific objectives were to:

1. Evaluatefuel briquette production technologies and their effects on energy efficiency.
2. Measureemissions of greenhouse gases,fine particulate matter and heavy metals in fuel briquettes.
3. Determinesocial-economic benefits accrued from production and use of fuel briquettes.
4. Evaluate potential environmental impacts in the production and use of fuel briquettes

1.3 RESEARCH HYPOTHESES

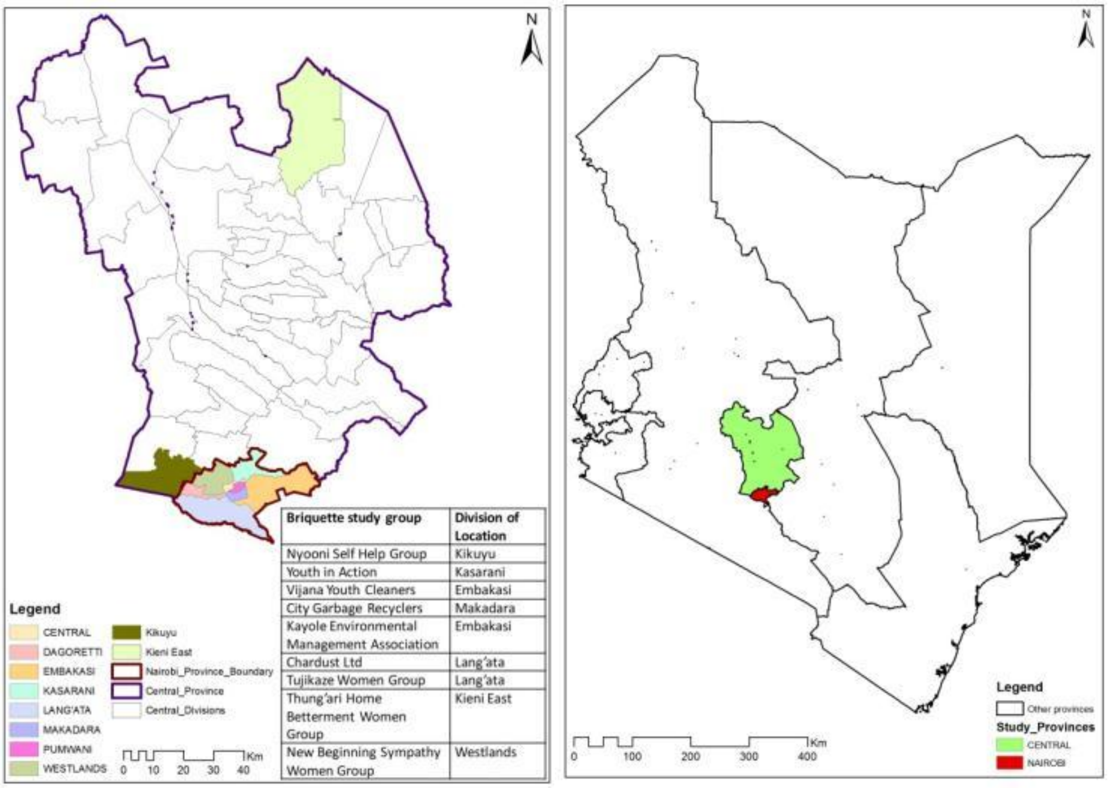
The study hypothesised that:

1. Fuel briquette production technologies have impacts on energy efficiency and emissions of carbon dioxide (CO_2), carbon monoxide (CO) and fine particulate matter ($PM_{2.5}$) emissions and amounts of heavy metals in the product.

2. There are socio-economic benefits in production and use of fuel briquettes.
3. There are potential environmental impacts in the life cycle of fuel briquettes from production to utilization.

1.4 STUDY AREA

The study was conducted in Nairobi, Kenya, which is located in southern Kenya on Latitudes 1^{o}10’’ S and $1^{o}20^{’’}$ S and Longitude 36^{o} 39’’ and 37^{o} 06 E at an elevation of 1670m above sea level and covers an area of 700 square kilometres. The city’s population is estimated at 3 million with an annual growth rate of 2.8% between 2000-2015 and constitutes 7% of the country’s population (GoK, 2010). Seventy five percent of the urban population growth is absorbed by informal settlements(UN-Habitat 2006). Nairobi employs 25% of Kenyans and 43% of the country’s urban workers. Sixty per cent of the city’s population lives in informal settlements and the numbers of urban poor projected to increase to 65 percent by 2015 (UN-Habitat 2006).The city generates about 3000 tonnes of waste, only 40% of which is collected and disposed properly (Kasozi and Blottnitz, 2010). Seventy percent of the waste is biodegradable (JICA, 1997). Kibera slum was chosen for a household survey because of its high population, poverty, lack of proper waste management services and presence of fuel briquetting activities. Kibera slum is located within the legal city boundaries of Nairobi, approximately seven kilometres southwest of the city centre. It is one of the most densely populated informal settlements in the world, and Africa’s largest slum. It is not clear as to how many people live in this slum as the census of 1999 had the figure at close to one million while the 2009 census stands at 0.4 million within 2.5 square kilometres. Seven of the groups that were studied and the private company were based in Nairobi while one group was located in Naro Moru town, 150 kilometres North East of Nairobi as shown in Figure 1.



Briquette study group	Division of Location
Nyooni Self Help Group	Kikuyu
Youth in Action	Kasarani
Vijana Youth Cleaners	Embakasi
City Garbage Recyclers	Makadara
Kayole Environmental Management Association	Embakasi
Chardust Ltd	Lang'ata
Tujikaze Women Group	Lang'ata
Thung'ari Home Betterment Women Group	Kieni East
New Beginning Sympathy Women Group	Westlands

Figure 1. Map of former Kiambu and Nairobi provinces showing location of studied self-help groups and Nairobi in the Kenyan context.

1.5 STRUCTURE OF THE THESIS

This thesis is divided into eightchapters. Chapter one, two and three comprises of background information, literature review and justification of the study and materials and methods respectively. Chapter four presents the socio-economic benefits that include income, employment opportunities and social networks in production and use of fuel briquettes and cooking efficiency of this fuel type as perceived by local communities.Chapter four addresses objective three and hypothesis two of the study.Chapters 5 presents fuel briquette production technologies practiced by the community based self-help groups and a private companyin Nairobi and surroundings and addresses objectives one and two and hypothesis one of the study. It establishes the effects of raw materials used and ratios of raw material and binders on combustion properties (calorific value, ash content and volatile matter), concentrations of chemical elements (Na, P, K, Fe and Al Cr,Hg and Pb)and emissions of CO_2, CO and $PM_{2.5}$ from briquettes.In chapter 6 fuel briquettes produced through experiments illustrate effects of (i) binders which include paper, soil, cowdung and gum Arabica,(ii) metal and wooden machines (iii) charcoal dusts from *Acacia mearnsii*, *Eucalyptus spp and Acacia xanthophloea*(iv) raw sawdusts from *Grevillia robusta, Pinus patula*and*Cupressus lusitanica*and (v) carbinized sawdusts from the three tree species in (iv) on combustion and emission qualities of fuel briquettes.Chapter six addressed objectives one and two of the studyand hypothesis one.Chapter 7 assesses the potential environmental impacts of fuel briquettes and addressed objective four and hypothesis three of the study. It presents a life cycle assessment that shows the climate impact as global warming potential (GWP) in kilogram CO_2 equivalent (Kg CO_2 Eq.) in cooking a traditional meal -a mixture of 500 grams of green maize (*Zea mays*) and 500 grams of dry common bean (*Phaseolus vulgaris*) commonly known as G*itheri* for a standard Kenyn household of five people using charcoal briquette. This section further indicates GWP in the specic processes of production and use of charcoal briquettes. The studymakes comparisons between common and improved practices in wood production and wood carbonization. It further compares cooking the standard meal with two reference fuels; charcoal and kerosene.Chapter 8 presents a summary of the findings and general conclusions and recommendations.

CHAPTER 2:LITERATURE REVIEWAND JUSTIFICATION

CHARCOAL PRODUCTION AND STRATEGIES TO ENHANCE ITSSUSTAINABILITY IN KENYA

Mary Njenga,Nancy Karanja, Cristel Munster, Miyuki Iiyama, Henry Neufeldt, Jacob Kithinjiand Ramni Jamnadass

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ABSTRACT

In sub-Saharan Africa 72% of urban and 98% of rural households use fuelwood for energy. In Kenya use of charcoal in urban areas has risen by 64% in two decades. Despite the charcoal industry providing employment to 500,000 people and generating over US$427 million that benefits grassroots communities, it has been kept out of the formal economies of this country. This review presents the status of the charcoal industry in Kenya, highlighting its contribution to livelihoods, production utilization and implications for the environment, policy issues and stakeholders' involvement. The review also proposes strategies to improve sustainability of this sector.

Key words: Environment, labour and livelihoods, governance and public policy, Sub Saharan Africa

2.1 GENERAL INTRODUCTION

This paper presents a review of existing information on the status of the charcoal industry in Kenya, highlighting its contribution of Ksh32 billion (US$427m) to the country's economy, support to the livelihoods of two million people along the value chain and demand by 82% of urban households and 34% of rural households. The paper also illustrates the main source of wood used in charcoal production as being from people's own farms and private land contrary to the belief that most charcoal originates from protected forests. Discussed also in this review are the charcoal production techniques and their environmental implications, efficiency in the use of charcoal, policy issues and stakeholders in the charcoal industry. The paper also proposes strategies to address some of the limitations highlighted along the value chain in order to make the sector sustainable.

Growing energy requirements is one of the major challenges facing the world today. The poor and middle income populations who are the majority users of wood charcoal cannot afford to use electricity and/or Liquid Petroleum Gas (LPG) for cooking because of the high investments in fuel and cooking appliances (Mugo *et al.* 2007).As living standards rise and urban areas expand, households and small-scale industries in many developing countries, especially in sub-Saharan Africa (SSA), are using charcoal more and more for cooking as other sources of energy such as electricity are expensive. In developing countries charcoal is mainly used in urban areas and its use is estimated to increase at 6% a year, which incidentally is proportional to the rate of urbanization. Charcoal production and trade contributes to the economy by providing incomes and employment for men, women and children at the community level and saves foreign exchange that would otherwise be used to import cooking fuel. Compared to firewood, charcoal has several advantages. For example Fuwape in 1993 found five-year-old *Leucaena leucocephala* and *Tectona grandis* yielded charcoal with a calorific value of 24.15kJ/g and 26.4 kJj/g respectively, compared to 13.45 kJ/g and 13.96 kJ/g from firewood. Charcoal is easy to transport as it has lower weight in respect to energy content, burns evenly for a long time and is less smoky. Hence there is no doubt that the charcoal trade will expand in the foreseeable future. It will continue to be the main and, in some cases, the only source of energy for millions of people in the sub-Saharan Africa for a long time (Mugo *et al.* 2007).

However, charcoal has been kept out of the formal economies of many countries, partly due to lack of supportive data and information. Charcoal production is a big threat to biodiversity because it targets specific preferred species found in natural forests and woodlands, most of which are poorly managed leading to unsustainable harvesting. In drier areas, where the regenerative capacity is lower, unplanned and unmanaged charcoal production accelerates the processes that lead to desertification (Mugo *et al.* 2007). The absence of replanting practices accelerates desertification and land degradation (Mutimba and Barasa, 2005). Most charcoal producers in the country use inefficient carbonizations processing leading to wastage of wood and greenhouse gas emissions.

2.2 LIVELIHOOD AND GENDER ASPECTS OF CHARCOAL

In comparison to other sectors in Kenya, charcoal is ranked forth after tourism, horticulture and tea. It represents an estimated annual market value of over Ksh32 billion (US$427m), almost equal to the Ksh35 billion (US$467m) from the tea industry (Mutimba and Barasa, 2005). It is a sector that supports communities at the grassroots as all the cash generated from it benefits poor Kenyans and circulates within the Kenyan economy, while for example 50% of that from tea goes to multinationals. The charcoal industry involves 200,000 people in production, of whom 84% are male and 16% female creating employment opportunities especially for rural young men. The number of charcoal producers alone is comparable to the government's teaching work force of 234,800 (Mutimba and Barasa, 2005). The cost of producing charcoal has been estimated at Ksh159 (US$2) and producers sell at Ksh260 (US$3) making a profit of 40% at farm gate which is too low compared to the consumer price of about Ksh1000 (US$13) per bag of approximately 90kgs. There are 300,000 persons involved in transportation and vending, comprising 86% male and14% female and 43% male and 57% female respectively. Selling of charcoal mainly takes place in the urban areas providing the highly needed income to low income women whose sales involves small quantities measured using tins but to a large number of buyers. Producers earn an average monthly gross income of Ksh4,496, (US$60) vendors Ksh 7,503 (US$100) and transporters Ksh11,298 (US$151) respectively (Mutimba and Barasa, 2005. Four percent of those involved in this industry are children. The average number of dependants supported by those involved in production, transportation and vending is estimated at two million (Mutimba and Barasa, 2005).

2.3 CURRENT DEMAND FOR CHARCOAL AS A FUEL SOURCE – AND FUTURE TREND

Though still less relative to firewood in most of Asia, charcoal use is becoming a much larger part of the woodfuels total in Africa and South America. It is predicted that charcoal will replace use of firewood in urban areas. Like in other parts of the region, charcoal demand in Kenya is high among urban households as shown in Table 1. In sub-Saharan Africa, over 72% of urban and 98% of rural households use fuelwood for energy (Bailis *et al*. 2005). In Kenya, between 1.6 and 2.4 million tons of charcoal are consumed annually, with a per capita consumtpion of 156kg and 152kg for urban and rural areas respectively (Mutimba and Barasa, 2005) (Table 1).

Table 2.1. Charcoal consumption in the East and South African region

Country	Annual consumption (million tons)
Kenya	1.6-2.4*
Ethiopia	0.23[+]
Zambia	0.7[$]

Source: *Mutimba and Barasa 2005; [+]Yigard 2002; [$]Chidumayo et. al., 2002.

As in other countries in the region, charcoal use in Kenya is mainly in urban areas and is on the increase (Table 2.)

Table 2.2. Charcoal consumption in Kenya

Type of user	1980	2000
Percent households at national level	8	47
Percent urban households	50	82
Percent rural households	37	34

Source: Mutimba and Barasa 2005

Out of the 1.6-2.4 million tons of charcoal consumed in Kenya annually, 10% goes to the capital city, Nairobi. The situation is similar in Tanzania, where 80% of charcoal produced is used by urban households (Ngeregeza, 2003). In Ethiopia, 70% of total production was found to be used in towns, supplying 97% of household energy needs (Yigard 2002). Charcoal use in Zambia is reported to have increased by 4% between 1990 and 2000 and 85% of urban households use charcoal in the country (Chidumayo, et. al., 2002). Hence substituting for charcoal for cooking is not a viable option in the short and medium term because of the high cost of both electricity and LPG and cooking appliances. For example in the year 2000, while the cost of cooking with charcoal was US$150 per household per year, the cost of cooking with electricity and LPG was estimated at US$740 and US$397 per household per year respectively. Most hotels and restaurants also prefer charcoal for roasting meat.

2.4 SOURCES OF CHARCOAL

Estimates from two studies show that sourcing of wood for charcoal burning from people’s own farms and private land has been on the increase, contrary to the belief that most charcoal originates from protected forests, as shown in Table 3.

Table 2.3. Sources of wood for charcoal production in Kenya

Source of wood	2003 %	2005 %
Own farm	40	44
Private land	40	38
Government or county council land	15	13
Communal land	5	5

Source: Mutimba and Barasa 2005

However, for fear of legal consequences and threat to their livelihoods, charcoal producers may be afraid to reveal the actual sources of the charcoal and such findings on sources of wood used for charcoal production therefore need to be treated with caution as they may misadvise efforts on natural resource management. Sourcing of charcoal from non-government land is common in the region. For example in Uganda, charcoal is generally produced on non-state land.

Charcoal production from people’s own farms is carried out by landowners in high potential areas who grow trees for various purposes ranging from fruit production, crop shade, firewood, fodder, live fencing, building and construction. Pruning’s and stumps are mostly used for charcoal production at a small scale (Mutimba and Barasa, 2005). In other cases, charcoal is a by-product of other activities such as land clearing for agricultural purposes, where for instance outsiders are invited to manually clear land and in return use the trees or shrubs to produce charcoal as a form of compensation. In this case production is often on a large scale and is common in wheat producing areas where large tracts of land are cleared to make room for production of wheat and barley, as in Narok District (Mutimba and Barasa, 2005). In marginal rainfall areas, communities clear and produce charcoal from the invasive *Mathenge (Prosopis juliflora)* to save pastures for their livestock. One large-scale private company, Kakuzi Ltd, produces charcoal from stumps of Eucalyptus spp after the tree is cut for production of posts.

Illegal charcoal production from protected government lands takes place adjacent to forests, in such districts as those bordering Mt. Kenya Forest, Mt. Elgon Forest, Kakamega Forest, Mau Forest and along some sections of the Mombasa Road, and this contributes 13% of total charcoal production (Mutimba and Barasa, 2005). With proper enforcement this could be reduced to less than five percent (Mutimba and Barasa, 2005).

Nearly all charcoal consumed in Kenya and elsewhere in sub-Saharan Africa (SSA) is made from local tree species. Over 100 tree species are used in charcoal production in Kenya. *Acacia* species (A*cacia tortilis, A. nilotica, A senegal, A. mellifera, A. polyacantha and a. xanthophloea*) are the most widely used (38%) and preferred (45%). Other popular species include Croton, Olea, Manilkara, Mangifera, Eucalyptus and Euclea (Mutimba and Barasa, 2005). Charcoal from hardwood is preferred because of its high density and calorific value (Mugo et al., 2007).

Kenya’s deficit in biomass energy has risen from 46% in 1980 to 57% in 2000. In Kenya it is estimated that commercially-grown trees can produce 18 tonnes of charcoal from one hectare. About 135,000 ha of fast-maturing tree species will be required every year to meet the current demand of 2.4 million tons (Mugo et al., 2007). Other countries both in the developed and developing world are also promoting the production of charcoal briquettes from biomass waste to supplement charcoal.

2.5 IMPACTS OF CUTTING TREES TO PRODUCE CHARCOAL

To satisfy Kenyans annual charcoal demand about 22 million cubic meters of wood is carbonized, resulting in deforestation of both rangeland and forests. Biodiversity is the basis of ecosystem health and of the provision of ecosystem services But one hundred species per million are lost per year (Rockström *et al.* 2009). The total area under woodland in Kenya is estimated at 48.6 million hectares. Of these, 1.3 million are under natural forests, 0.17 million are forest plantations, 9.5 million are farmlands. Arid and semi-arid lands which are a major source of charcoal in Kenya cover 80% of the land and cattle production is one of the most important livelihood Deforestation and land degradation are some of the challenges Kenya needs to address to achieve Millennium Development Goal (MDG) 7, ‘Ensure Environmental Sustainability’. In Kenya annual deforestation rate for 1990 – 2005 was 12,000 ha / year while the total remaining forest stood at 3.5 million ha. In Mau forest for example one of Kenya’s water tower, one quarter or some 100,000 hectares – has been destroyed since 2000. Sourcing charcoal from protected governmental land among other factors contributes to destruction of forests which are already threatened. Charcoal producers for example destroy the forests as they use traditional kilns which are poor in biomass conversion and cause fires which in most cases destroy the areas surrounding the charcoal production sites. Because this activity is done illegally effective monitoring and control of implications of charcoal production on forests and biodiversity has been difficult to achieve.

2.6 METHODS OF CHARCOAL PRODUCTION AND ENVIRONMENTAL IMPLICATIONS

The charcoal production process involves burying wood under a mound of earth and igniting it underneath so that there is a limited air supply; this is the traditional earth kiln. The wood is partially denied oxygen and in the burning process is converted to charcoal, carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4) and particulates (Pennise *et al.* 2001). Factors that affect charcoal production efficiency in this technique include; design of the kiln, tree species used, moisture content of wood, arrangement of wood in the kiln and monitoring of carbonization process which explains the wide range of 10-20% obtained in earth kilns. Research showed that 99% of charcoal producers in Kenya use traditional earth kilns, which are cheap as they only require labour to construct. On the other hand they have low efficiency of 10-20% in converting wood to charcoal compared to improved retort kilns with 45% efficiency (Mutimba and Barasa, 2005). KEFRI has developed a manual based on four charcoal processing technologies, and this indicates that improved earth kilns, a portable metal kiln, a drum kiln and the Cassamance kiln could give yields ranging between 27-30%. Improved production techniques requiring more labour and cost but the quality of charcoal is better compared to earth kilns as the newer methods have better control of the carbonization process.

The impacts of poor carbonization techniques include wastage of woody biomass, low incomes for charcoal producers and high levels of pollution and green-house gas emissions (Mugo *et al.* 2007). A study on emissions of greenhouse gases and other airborne pollutants from charcoal production in Kenya and Brazil showed thatemission factors, expressed as grams of pollutant per kilogram of charcoal produced, ranged from 543 to 3027 for CO_2 and143-373 for CO. On average, wood carbon is approximately diverted as follows: 51% to charcoal, 27% to CO_2, and 13% to products of incomplete combustion (PIC). Due to the higher global warming potentials (GWPs) of PIC relative to CO_2 on a carbon atom basis, such kilns may contribute to greenhouse gas emissions, even when the wood is harvested sustainably (Pennise *et al.* 2001). Furthermore, use of inefficient earth kilns contributes to at least 0.77-1.63kg of carbon dioxide per kilogram of charcoal produced. This amount of emissions can be reduced by up to 75% when improved and more efficient retort kilns are used.

2.7 EFFICIENCY IN USE OF CHARCOAL AND ITS EFFECTS ON CLIMATE CHANGE AND PUBLIC HEALTH

Combustion of charcoal and inefficiency in its use as a source of cooking and heating energy contributes to emission of greenhouse gases as well as substances that are harmful to health. Recent calculations by the Edinburgh Centre for Carbon Management showed that one ton of charcoal produced and consumed generates nine tons of CO_2 emissions. This implies that out of the 1.6-2.4million ton of charcoal produced and consumed in Kenya, 14.4 to 21.6million tons of CO_2 are emitted into the atmosphere every year, contributing to climate change. Combustion of biomass emits pollutants that cause over

1.6 million annual deaths globally, which translates to one death every 20 seconds or 400,000 in SSA per year (Bailis et al., 2005). Most of these deaths are among children (56%) and women.

In Kenya about 85% of households in urban areas use the improved Kenya Ceramic Jiko, which has an energy conversion efficiency of about 33-35% compared to 10-15% obtained in traditional stoves.Use of the Kenya Ceramic Jikoenables poor urban households to make financial savings of 26% of annual household income. Another type of stove that could contribute to a reduction in the quantity of charcoal used is the fireless insulation-based cooker (Mugo *et al.* 2007). A fireless cooker completes cooking that is initiated by another stove such as the KCJ. Tests have shown that this cooker despite cooking food for a long time can reduce cooking energy consumption by 50%. This suggests that a combination of ceramic stove and fireless cooker can reduce household charcoal consumption by 75% (Mugo *et al.* 2007). Fireless cookers are made from a simple basket, insulated with local resources such as banana leaves or old clothes. Use of improved stoves could reduce the negative health effects of using of charcoal, where for example respiratory infections in children and women fell by 60% and 65% respectively when the KCJ was used.

2.8 POLICY ISSUES AND STAKEHOLDERS IN THE WOOD CHARCOAL INDUSTRY

Due to lack appropriate taxation system, it is estimated that the Kenyan economy losses about Ksh5.1 billion annually based on the 16% value added tax (Mutimba and Barasa, 2005). The only revenue to the government is through cess collected through charcoal by-laws approved by the Ministry of Local Government and business permits (trade licenses). To make charcoal sector commercially acceptable. There is need for efficient systems to implement the existing rules and regulations on charcoal production, processing and movement currently and also sensitization and awareness creation of relevant stakeholders.

The Ministry of Energy has the mandate to provide adequate energy sources in Kenya. However, no charcoal law exists although a Renewable Energy Policy and Bill are being developed. The Energy Act 2006, section 103, mentions charcoal as one of the form of biomass energy that the Ministry of Energy is mandated to promote, concerning its development and use technologies. The Environmental Management and Coordination Act 1999, paragraph 49, specifies that the National Environmental Management Act promotes use of renewable energy sources, of which charcoal is one. This is suggested to be done through encouraging private farmers, institutions and community groups to plant trees and woodlots. Currently two documents are used to control charcoal production and transport, a certificate of origin and a movement permit. Acquisition of the two documents is free of charge.

The Forest Act of 2005 legalized charcoal as a forest product and gave the Kenya Forest Service the mandate to enforce and regulate charcoal-making as one of the forest utilization activities. The Ministry for Forestry and Wildlife, under section 59 of the Forests Act, 2005, developed forest (charcoal) regulations. The regulations reemphasize that commercial charcoal production and transportation will require a valid license or permit that will be issued by the Kenya Forest Service. Exportation and/or importation of charcoal or charcoal products will require possession of a permit issued under the forests (charcoal) regulations, 2009. A lesson could be learnt on controlling charcoal export from the case of Sudan where charcoal export in Sudan is currently restricted to specific places and the Forest National Corporation sets the minimum price and export of high quality charcoal, mainly acacia, is limited to 5,000 tons a year (Mugo *et al.* 2007).

The Ministry of Energy has been conducting technical capacity building on agroforestry for fuelwood and energy conservation strategies such as use of appropriate kilns through 10 energy centres located in different parts of the country. Technical capacity building has also been provided to communities by other Ministries such as those ofAgriculture, Livestock and Fisheries Development and Education as well as Forestry and Wildlife, on tree planting, management of range vegetation and efficient energy utilization.

Research and development work in the charcoal industry has also been going on in the country where for instance Kenya Forest Research Institute, Kenya Forest Products Research Centre-Karura has developed a manual on improved charcoal-making technologies. The government has been commissioning studies around the charcoal industry, as for example the one conducted by the Ministry of Energy in 2002, and another by Energy for Sustainable Development AFRICA in 2005 (Mutimba and Barasa, 2005). Other organizations both public and private involved in charcoal-related research and development include the World Bank, Food and Agriculture Organization (FAO), Danish International Development Agency (DANIDA), Swedish International Development Cooperation Agency (SIDA), United Nations Development Program (UNDP) and Global Environmental Facility (GEF), Regional Land Management Unit (RELMA), World Agroforestry Centre (ICRAF), Universities in Kenya and outside, Practical Action, Thuiya Enterprises Ltd and Policy Innovation System for Clean Energy Security (PISCES). The Green Belt Movement and Kakuzi Ltd have been instrumental in tree planting for fuelwood, while sugar factories, the Coffee Planters Cooperative Union, (KPCU) and Chardust Ltd have been working on fuel briquette production through recycling organic waste and agricultural residues. Other important stakeholders in charcoal include producers, transporters and vendors as discussed earlier under livelihood and gender aspects of charcoal.

2.9 INTERVENTIONS THAT COULD TURN CHARCOAL PRODUCTION INTO A SUSTAINABLE SECTOR

This section of the paper presents proposals for interventions in carbonization and utilization techniques, agroforestry for charcoal production, recycling of charcoal dust for production of energy fuel briquettes to complement charcoal, and policy aspects that would turn this important industry into a sustainable sector.

2.9.1 Efficient production and utilization processes

The Kenya’s current charcoal production is a threat to the environment as over 99% of it still uses inefficient carbonization processes (Mutimba and Barasa, 2005). Adoption of efficient charcoal production kilns would in addition to minimizing gas emissions, reduce consumption of wood. This could be achieved through building technical capacity of charcoal producers who also need microfinancing systems to adopt appropriate technologies supported by effective governing systems. Designing of mobile, efficient charcoal kilns would minimize transport costs, while kilns for small-sized wood and branches would be necessary for farmers, who are able to source wood from neighbours.Training materials are available, for example the easy-to-use manual on improved kilns by KEFRI, although much more research is required to improve the efficiency of kilns as the highest efficiency reported in the country stands at 45%. Kenya already has improved stoves on the market, such as the Kenya Ceramic Jiko (KCJ). The government is in support of this strategy as the energy strategies Sessional Paper No. 4 of 2004proposes increased adoption of efficient charcoal stoves from 47% to 80% by 2010, and to 100% by 2020 in urban areas. The targets are 40% by 2010 and 60% for rural areas. The same paper announces the target to increasing efficiency of charcoal stoves from 30-35% to 45-50%.Use of these efficient stoves has a potential to reduce demand for charcoal as well as to mitigate climate change and indoor air pollution. For example, retort kilns reduce Green House Gas (GHG) emissions by 75% (Adam, 2009).

A large number of charcoal producers could easily be reached for training on efficient carbonization processes through working with community based groups producing charcoal. The existing ten energy centres through which farmers are trained by the Ministry of Energy are important platforms that could be empowered for community technical capacity building. The country has a wide range of media, celebrities such as those in music and drama, public gatherings such as in churches and community meetings (*barazas*), all of which could serve as important channels for reaching consumers with messages on efficient use of charcoal.

2.9.2 Agroforestry systems for sustainable charcoal production

Many view the charcoal industry as a threat to natural resources and climate and their fear is real as revealed by Mutimba and Barasa, (2005), who found that over 75% of charcoal in the country is produced unsustainably. Ironically, the charcoal industry could save the environment that it now threatens if communities and private practitioners grew trees for charcoal as well as harvested trees sustainably through proper management plans. There is potential to improve tree cover and produce charcoal, through adoption of short rotational agroforestry systems. The Kenya Forestry Research Institute (KEFRI), showed that a six year old *Acacia xanthophloea* tree produced charcoal with calorific value of 33kJ/g. The fixed carbon was 70%, within the range of good quality charcoal, which is 50-95%. For example *Terminalia orbicularis* and *Commiphora Africana*, which are drought resistant, abundant in the Arid and Semi-Arid Lands (ASALs) and regenerate easily from cuttings, have a potential that could be exploited for charcoal production in ASALs. Another study on suitability of *Acacis drepanolobium* for sustained charcoal yield in Laikipia, Kenya showed that over a 14-year cycle while the trees are allowed to coppice naturally, a minimum of 3.0 tons ha^{-}1 of charcoal could be produced using the traditional kiln. The tree is suitable for charcoal production in arid and semi-arid lands as it occurs in almost mono-specific stands in high densities over vast areas, coppices readily when harvested or top killed by fire and it's hard wood makes good quality charcoal. On the other hand as most charcoal is consumed in urban areas, there is need for establishment of private agroforestry systems in peri-urban areas and opportunity cost studies on the use of peri-urban areas carried out. However adoption of agroforestry systems for charcoal production will depend on availability of labor, land and money among other factors.

Farmers through government technical extension services, research and development organizations' work could be advised on appropriate tree and shrub species, optimal tree management and rotation periods, as recommended by stakeholders during a charcoal seminar held at World Agroforesry Centre {ICRAF} Farmers could be encouraged to form or join Community Forest Associations (CFAs) that will coordinate sourcing of seeds and seedlings, planting, management, awareness creation and monitoring of charcoal production as a cash crop. The CFA's would also provide socioeconomic benefit to communities such as encouraging equity, conflict resolution, poverty reduction and sustainable utilization of forest and tree products. There are 347 CFA's in Kenya which are mainly located in the important forest regions. Membership in these CFA's varies between 30 to 3000 as they are made up of different self-help groups. Ranches and private companies could improve sustainability in charcoal productionthrough formulating tree management plans and being provided with tax incentives by the government to plant trees for charcoal production.

The other option for sustainable charcoal production would be support of the on-going harvesting of the invasive *Prosopis juliflora* species as a strategy to restore pastureland in the affected areas. Global concern about deforestation caused by fuelwood shortages prompted introduction of *Prosopis juliflora* to the Lake Baringo area in the early 1980s. *Prosopis juliflora* is in the World Conservation Union (IUCN)'s new list of 100 world's worst invasive alien species (Mwangi and Swallow, 2005). Unlike some other parts of the world where it has been introduced, *Prosopis juliflora's* potential benefits have not been captured and few people in the areas where it is found in the country realize net benefits from the widespread presence of the tree.*Prosopis juliflora* produces high quality charcoal although its production is faced with the challenges of harvesting the branches as they have strong thorns that are hard to cut and wear down simple cutting tools(Mwangi and Swallow, 2005). However a project funded by the Ministry of Energy and supervised by KEFRI is supporting the community in Marigat, Baringo, District to harvest *Prosopis juliflora*for charcoal production for sale locally and for export.

Large plantations in low-population areas and under-used land are some examples of how agroforestry systems are being adopted for sustainable charcoal production in Brazil (Rosillo-Calle et al, 1996) and Sudan (Ibrahim, 2003). In the Democratic Republic of Congo, about 8000 hectares of *Acacia auriculiformis* were planted from 1987 to 1993 and in 1998 the Mampu plantation was divided into 25-hectare plots for 320 farming families. The agroforestry woodlots were based on improved fallows, drawing on traditional slash-and-bum farming. Total charcoal production from the plantation ranged from 8 000 to 12 000T/year in addition to 10 000 T/year of cassava, 1 200 T/year of maize and 6 T/year of honey**.** Gross annual revenue for the country from charcoal alone amounts to 2.6 million US dollars with owners of these agroforestry plots earning at least a quarter (Bisiaux, *et al.* 2009). This helps cover a large share of urban needs for renewable energy while creating rural employment.

2.9.3 Recovery of charcoal dust/fines for energy fuel briquette production

Between 10-15% of charcaol ends up as waste in the form of charcoal dust along the charcoal value chain. This occurs during transporation and at wholesale and retails stalls In Narobi for exmaple about 70 tons of charcaol dust are produced daily at the charcaol wholesale and retail stalls. The term waste refers to something that is useless or worthless and one way of recovering charcoal dust is through production of energy fuel briquettes. Production of energy fuel briquette involves collection of combustible materials and compressing them into a solid fuel product of any convenient shape and this is then burned like wood or charcoal. Another option in briquette-making is harvesting of tree pruning’s. Kasigau NGO producerin Lamu set –up an harvest twigs from fast-growing trees at the rate of re-growth to ensure sustainability. In the scheme twigs are carbonized mixed with a binder to make briquettes. Fifty percent of briquette-making enterprises in the country are community based organizations with about 25 members’ each and mostly comprising women and youth. Others involved in briquette production include non-governmental organizations and private companies. The main raw material used in energy fuel briquette production is charcoal dust, which is bound with either biodegradable paper or soil. About 82% of briquette producers in the country use manual machine presses, 25% use electricity and 10% use other means including bare hands. The briquettes are used in homes, food kiosks and hotels, institutions such as schools, chicken hatcheries and bakeries.

2.9.4 Formalization of charcoal industry

Legalization and reinforcement of the charcoal regulations should be aimed at offering an enabling legal framework that promotes commercial charcoal production and licensing for revenue, enterprise-based approaches for poverty reduction, smallholder/private tree-growing, woodfuel-energy conserving technologies, improved agricultural productivity and ecological sustainability. In Malawi for example stagnant policies based on charcoal 'bans' and fuel-substitution were not effective and it was learnt that polices need to be transformed into proactive and realistic ones acknowledging woodfuel dominance and its socio- economic importance (Zulu, 2010). To protect the country's biodiversity the charcoal regulations prohibits production of charcoal fromendangered, threatened and protected plant species and requires reforestation or conservation plans for the area where trees will be managed for charcoal production. The regulation system will also address the lack of standards to regulate quality, weight and size of the charcoal bags entering the market which for instance has caused buyers and sellers to pay the same amounts for different sizes of bags. Community based organizations have been entry points for many research and development interventions in the country but this has been absent in the charcoal industry due to its informal set up but the groups can now take advantage of the legal status of the industry. Legalization and regulation of this sector through the coordination of the government will ensure that the policy framework works effectively.

2.10 AREAS FOR FURTHER RESEARCH

- There is scant information on the origin of the charcoal supply. More precise and reliable data on sources of charcoal and how it is produced are needed so as to evaluate the implications on agro-ecosytems and the environment.
- The charcoal industry is an important economic activity but there is need for more data to illustrate the flow of charcoal and money. These include gathering gender-disaggregated data on amounts transported from source to market, mode of transportation, players in the marketing chain and how they are organized, amounts traded and prices, cost-benefit analysis for pricing, and the challenges, constrains and opportunities along the market value chain.
- Production and utilization methods are inefficient and there is need for more data on their cost-effectiveness and sustainability. Data is also missing on implications of charcoal production on forests and biodiversity.
- There is need for research on alternative sources of bioenergy so as to save threatened tree vegetation cover. The potential to produce energy fuel briquettes through compacting tree by-products such as charcoal dust and sawdust and agricultural residues, all of which are plentiful in some ecological zones, needs to be evaluated.

2.11 CONCLUSIONS AND RECOMMENDATIONS

In sub-Saharan African countries, wood charcoal is the main source of cooking energy, with highest consumption being in urban areas. This trend is likely to persist due to its affordability and the high urbanization rates. The charcoal industry supports livelihoods of men, women and children at the grassroots level. Government involvement through development of supportive policies and regulations such as provision of tax incentives to private companies to grow trees for charcoal and establishment of forests specifically for charcoal is an important option that offers great opportunity for sustainable charcoal production Similar incentives would encourage farmers to engage in establishment of woodlots and on-farm forestry, using appropriate tree and shrub species for charcoal production and following improved technologies. Options should also be evaluated with farmers to seek their priorities in using charcoal dust either for soil amelioration or in making fuel briquetting to meet their cooking energy needs.

The government, development practitioners and partners need to carry out further action research and disseminate information to charcoal producers and users on appropriate production and utilizations processes. These include technologies with high biomass conversion rates and low gas emissions, such as improved kilns and cooking stoves. The waste generated in the charcoal value chain, which otherwise degrades the environment, has a potential to address the increasing cooking and heating energy demand through processing it into fuel briquettes. In order to achieve inclusive development there is need for the application of gender- responsive situation analysis, designing and planning, as well as implementation and impact monitoring and evaluation methods along the charcoal value chain. Awareness raising and training among law enforcement bodies and other stakeholders on charcoal regulations, to clear the misconception that its production and transportation is illegal.

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CHAPTER 3: MATERIALS AND METHODS

3.1 SURVEYS ON PRODUCTION METHODS AND USE OF BRIQUETTES BY LOCAL COMMUNITIES

Asurvey was conducted among seven community self-help groups (SHGs) in 2010 comprising of charcoal briquette producing SHG's comprised all those identified and locatedusing an existing database on self-help groups involved in waste management in Nairobi (Njenga *et al*. 2010). A checklistwas administered to members of the groups through focus group discussions. These discussions were to document types, amounts and sources of raw materials and binders and production methods used in briquette making. A detailed survey was conductedon use of charcoal briquettes at Kibera slums among 199 households and the questionnaire used is presented in Appendix 1.Fifty households were selected along four footpaths within a 250-metre radius of a charcoal briquette production site at Gatwekera village, in which every fifth household on those paths was interviewed. The sample size is about 5% of households within the study area of 0.1km^{2}using the census data of 2009 (GoK, 2010).

3.2 EXPERIMENTAL DESIGN

The experiments were carried out at the University of Nairobi to test (i) four binders namely paper, soil, cowdung and gum Arabica in binding *Acacia mearnsii* charcoal dust fuel briquettes, (ii) two types of machines which included metal and wooden press for production of *Acacia mearnsii* charcoal dust fuel briquettes bonded with either paper, soil, cowdung or gum Arabica (iii) charcoal dusts from three tree species which included *Acacia mearnsii*, *Eucalyptus spp and Acacia xanthophloea* bonded with paper as the binder, (iv) raw sawdusts from three tree species namely *Grevillia robusta, Pinus patula*and*Cupressus lusitanica*using gum arabica as a binder and (v) carbonized sawdusts from the three tree species in (iv) above bonded with gum arabica. Charcoals from *Acacia mearnsii*,*Eucalyptus spp* and *Acacia xanthophloea* were considered as the control. The statistical design had 40 replicates for each type of fuel briquette and charcoal.

3.3 DETERMINATION OF COMBUSTION PROPERTIES OF BRIQUETTES

The combustion properties include ash content, calorific value and volatile matter. Forty samples of each type of briquette and wood charcoal as a control were analysed using Infrared (IR) Spectroscopy following procedures described by Shepherd and Walsh (2007). In Near-infrared (NIR) and Mid-infrared (Mid-IR) the MPA Multi Purpose FT-NIR Analyzerand Tensor 27–HTS-XTBruker FTIR equipments were used respectively. A double sampling approach was used whereby a spectral library of the total 40 samples per type of fuel was first established and then a representative subset samples were selected based on the chemical and physical spectral diversity in the library(Shepherd and Walsh 2007). The subset of samples were analysed for ash content, calorific value and volatile matter following procedures described by Findlay(1963). Volatile matter was measured using 0.5g of the sample which was heated in a furnace at 800 ^{o}C for five minutes. Volatile matter was then expressed as the percentage of loss of weight of the original sample. The ash content was determined the same way as volatile matter but this time the sample was heated for 1.5 to 2 hours. Calibration based on the subsetsamples were used to predict combustion properties for the entire sample spectral library as described by Shepherd and Walsh (2007).

3.4 DETERMINATION OF CHEMICAL ELEMENTS IN BRIQUETTES

Asubset of 50 samples (25%) from community groups were analysed for multiple elements using the S2 PICOFOX^{TM} (Bruker AXS Microanalysis GmbH) total x-ray fluorescence (TXRF) spectrometer to establish presence and possible sources of heavy metal contamination in briquettes. Each sample was milled to <50 µm using a micronising mill (McCrone, Westmont, U.S.A.) and amount of 45 mg of each finely ground sample was mixed with 2.5 ml of Triton X-100 (Fischer Scientific, UK) solution (0.1 vol.-%) to form a suspension and then spiked with 40 µl of 1000 mg l^{-1} Selenium (Fluka Analytical, Germany) as the internal standard. Triton®-X 100, an organic compound, applied for TXRF sample preparation, enhances the homogeneity of samples (Stosnach, 2005). The solution was then mixed well using a digital shaker and 10 µl of the solution immediately dispensed on to a clean siliconized quartz glass sample carrier and dried on a hot plate set at 40 ^{0}C for 5-10 minutes. Sample analysis time was about 10 minutes per sample while the data acquisition time was set at 1000 s per sample. The interpretation of the TXRF spectra and data evaluation was performed using the software program SPECTRA 6.3 released by Bruker and included with the S2 PICOFOX spectrometer.The benefits of this analytical technique are, that it is non-destructive, requires only extremely minute sample amounts, and the analysis, including sample preparation and quantification, is easy to handle. In the past TXRF analysis was restricted to large scaled instruments, which demand the usage of cooling water and liquid nitrogen (Stosnach, 2005).

3.5 MEASURING CONCENTRATIONS OF CARBON MONOXIDE (CO), FINE PARTICULATE MATTER ($PM_{2.5}$) AND CARBON DIOXIDE (CO_2) FROM BURNING BRIQUETTES

The concentration of CO, fine PM $_{2.5}$ and CO_2 were measured from burning an amount of fuel that filled the small-sized energy saving cook stove called Kenya Ceramic Jiko (KCJ) as practiced by households. Concentration of CO, fine PM $_{2.5}$ and $CO_2$from burning charcoal in the same JCK were measured.Concentration of CO, fine PM $_{2.5}$ and CO_2were also measured from burning kerosene in a kerosene stove as practiced by households.The types, amounts and length of burning period for each briquette were established. Charcoal and kerosene were used as control. An aluminium cooking pot containing water with dimension that fitted the cook stove was placed on top, as practiced by households. Measurements were carried out in triplicates in a kitchen measuring $9m^2$ with one door and two windows simulating household cooking conditions. The measuring equipments were hanged with a rope one metre high aboveand to the side ofthe cooking pot and stove, simulating the height of a person cooking.Carbon monoxide was measured at 10 seconds intervals using EL-USB-CO carbon monoxide data logger, DATAQ Instruments. Fine particulate matter measurements were taken per minute using a particulate matter meter, UCB, Berkeley Air Monitoring Group. Carbon dioxide was measured at intervals of 5 minutes using Taile 7001 Carbon Dioxide and Temperature, LASCAR.

3.6 COOKING EFFICIENCY TESTS

The cooking efficiency tests were carried out at the Human Needs Project (HNP) open ground at Kibera slum, Nairobi in early 2012. The amount of fuel used and time taken to cook the meal were calculated. The cooking was conducted by 23 women who lit the cook stoves, added water and fuel as required and tasted when the food was completely cooked. Eight hundred and fifty grams of charcoal briquette, 890 grams of wood charcoal and 0.36 liters of kerosene were used separately to cook the strandard meal. Cooking with charcoal briquette and charcoal was done using the commonly used improved cook stove known as Kenya Ceramic Jiko (KCJ) and for kerosene, the cook stove from India used in Kenya was used. The traditional meal cooked was a mixture of 500 grams of green maize (*Zea mays*) and 500 grams of dry common bean (*Phaseolus vulgaris*) commonly known as G*itheri* for a standard Kenyan household of five people (GoK, 2010).

3.7 LIFE CYCLE ASSESSMENT (LCA)

Life cycle assessment (LCA) was applied following procedures described by Buamann and Tillman (2004)to establish potential environmental impacts of charcoal briquette as a cooking fuel in its different stages of current production and use system in Kenya. The (LCA) was conducted in following ISO 14044:2006 guidelines as illustrated in Buamann and Tillman, (2004). The ISO 14044:2006 specifies requirements and provides guidelines for life cycle assessment (LCA) including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, relationship between the LCA phases, and conditions for use of value choices and optional elements. The functional unit was fuel used in cooking theabove mentioned traditional meal -a mixture of 500 grams of green maize (*Zea mays*) and 500 grams of dry common bean (*Phaseolus vulgaris*). Climate impact as $GWP_{100}$was calculated in kg CO_2 equivalent (CO_2 eq) per meal using SimaPro software (SimaPro 7.3.3, 2011). The SimaPro 7.3.3 program was acquired through a temporal 6 months renewable Faculty License at no cost. SimaPro is easy to use and provides quick results. The program assists in managing complex tasks while all the results remain completely transparent. The program allows one to create a new project and enter data as well as select data from the inbuilt Ecoinvent database at every process and create files with all product stages from which the program is ran. Once the product stage file is ran, the program calculates Kg CO_2e at each process or stage of the product as well as total amount along the life cycle. There were challenges in finding data on transport and refinery based on Kenyan situations in the Ecoinvent database due to few number of LCA's in developing countries and use of data from Europe was the only option which was readily available in the Ecoinvent database. This challenge was also faced by scientists conducting an LCA on charcoal from sawmill residues in Tanzania (Sjolie, 2012).

The distinct processes in the LCA include common practices of sourcing wood from *Acacia depanolobium* native woodland savannas, wood carbonization using low efficiency earth mound kiln, transportation of charcoal to urban areas and use of charcoal briquette in cooking.The studyalso made comparisons with improved practices such as wood production in *Acacia mearnsii* plantation and wood carbonization using high efficiency mound kiln. It further compares cooking the standard meal with two reference fuels; charcoal and kerosene.

3.8 DATA MANAGEMENT AND ANALYSIS

Data was analysed using Microsoft Excel software for descriptive statistics such as mean and standard error. Genstart Edition 13 was used for One Way Analysis of Variance (ANOVA) (VSN International, 2012). ANOVA was carried out to test significant difference between the means of different types of briquettes. Significance difference between any two means was tested using the least significant difference of means (LSD) from the ANOVA results.One way ANOVA was carried out to tests significance difference in quality of (i) charcoal briquettes made from different binders and charcoal dusts of different tree species compared to pure charcoals from from *Acacia mearnsii, Eucalyptus spp and Acacia xanthophloea*, (ii) fuel briquettes made from a metal and a wooden machine (iii) sawdust briquettes made from raw and carbonized sawdust from *Grevillia robusta, Pinus patula*and*Cupressus lusitanica.*Tables of ANOVA results are presented in Appendix 1. Actual probability values have been presented as ‘p’ to show significance at confidence level of 95%. R^2 indicates coefficient of determination as a measure of the degree of linear association between two variables. R^2 may take on any value between 0 and 1.

CHAPTER 4: IMPLICATIONS OF CHARCOAL BRIQUETTE PRODUCED BY LOCAL COMMUNITIES ON LIVELIHOODS AND ENVIRONMENT IN NAIROBI, KENYA

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ABSTRACT

The residents of Nairobi, Kenya,use 700 tonnes of charcoal per day, producing about 88 tonnes of charcoal dust that is found in most of the charcoal retailing stalls that is disposed of in water drainage systems or in black garbage heaps. The high costs of cooking fuel results in poor households using unhealthy materials such as plastic waste. Further, poor households are opting to cook foods that take a short time to prepare irrespective of their nutritional value. This article presents experiences with community self-help groups producing charcoal briquettes from charcoal dust in poorer nieghbourhoods of Nairobi for home use and sale. Households that produced charcoal briquettes for own use and those that bought them saved 70% and 30% of money spent on cooking energy respectively. The charcoal briquettes have been found to be environmentally beneficial since they produce less smoke and increase total cooking energy by more than 15%, thereby saving an equivalent volume of trees that would be cut down for charcoal. Charcoal briquette production is a viable opportunity for good quality and affordable cooking fuel. Bioenergy and waste managementinitiatives should promote recovery of organic by-products for charcoal briquette production.

Keywords: charcoal, development, community based charcoal briquetting, cooking fuel, poor neighbourhoods,

4.1 INTRODUCTION

Growing energy demand is one of the major challenges facing the world. In Sub-Saharan Africa (SSA), over 72% of urban and 98% of rural households depend on fuelwood for energy (Bailis *et al*. 2005). Charcoalis the principal fuel that provides energy for 82% of urban and 34% of rural households in Kenya (Karekezi, 2002; MoE, 2002).Demand for biomassenergy for cooking is likely to increase with population growth and an increasing urbanization rate where the latter in Kenya is currently 6.3%. The annual per capita consumption of charcoal in Kenya is about150kg which translates to an annual national consumption of 2.4 million tonnes (Mutimba and Barasa, 2005) while available biomass energy fall short of meeting demand and the difference has risen from 46% in 1980 to 57% in 2000 (Mugo *et al.* 2007).Dependence on charcoal for cooking is similar in Tanzania, Zambia, and Ethiopia, where 80%, 85%, and 70% of urban households rely on it, respectively (Ngeregeza, 2003; Chidumayo, *et al*. 2002; Yigard 2002). The poor populations, who are the majority users of wood charcoal, cannot afford to use electricity and/or liquid petroleum gas (LPG) for cooking because of the high costs of fuel and related cooking appliances (Mugo *et al.* 2007).Combustion of bio-fuels emits pollutants that contribute to over 1.6 million annual deaths globally, of which 400 000 occur in sub-Saharan Africa (SSA) (Bailis, 2005). There is a need therefore to link knowledge on charcoal briquette quality to indoor air pollution.

Kituyi, 2004, describes this challenge facing poor householdsin accessing cooking energy as being shared by nations in SSA and he further argues that for the short and medium terms, any sustainable development solutions in the household energy sub-sector in Africa must necessarily focus on biomass energy technology development and dissemination.Due to the high costs of cooking fuel, poor households often use unhealthy materials such as old shoes, used plastic containers and old plastic basins (Gathui and Ngugi, 2010). Further poor households are opting to cook foods that take a short time to prepare irrespective of their nutritional value. For sustainable development and green economy to be achieved new and renewable energy sources, greater reliance on advanced energy technologies and sustainable use of traditional energy sources have been identified as key areas for global dialogue (UNEP, 2011).

Faced with poverty and unemployment, communities are turning tocharcoal briquette making through recovering charcoal dust, among other organic by-products. There is a loss of about10-15% along the charcoal supply chain in form of dust or fines as a result of breakages during handling and this dust is mainly found at the retailing and whole sale stalls.Charcoal dust poses disposal challenges.Most often, it is either dumped in open drainage systems or left as unattended heaps that risk environmental pollution.Biomass residues generated by wood-based industries in most developing countries have potential to supplement energy sources such as firewood, in domestic energy needs (Suarez *et al*. 2000). However, only a small proportion of the residues are used as fuel because of their high moisture content, low energy density and transportation costs (Nasrin *et al.* 2008). Densification of biomass residues into fuel briquettes presents an opportunity to reduce these drawbacks. Fuel briquettes are made by compressing biomass material such as charcoal dust, sawdust and other wood residues or agricultural by-products into a uniform solid unit (Sotannde *et al*. 2010a; Rousseta *et al*. 2011). Briquetting biomass is done using various techniques, either with or without binder. For charcoal and other biomass material that lacks plasticity, addition of a sticking or agglomerating material, preferably combustible is required to enable the formation of solid briquettes (Rousseta *et al*. 2011). Common binders are starch, gum arabica, soil, animal dung or waste paper. Biomass briquettes in the developing countries are mainly for domestic usage (Sotannde *et al*. 2010b).

Biomass residues generated by the wood-based industry in most developing countries have potential to alleviate cooking energy poverty as demonstrated in Cuba, Nigeria, Brazil, China, and Kenya (Suarez *et al*. 2000; Sotannde et al. 2010a; Rousseta *et al*. 2011; Gominho *et al*. 2012; Wamukonya and Jenkins, 1995).·Agricultural by-products are used in briquette production such as rice straw and rice bran in China (Chou *et al*. 2009), maize cobsin Thailand (Wilaipon, 2007) and coffee husks in Brazil (Felfli, *et al*. 2010). Adoption of fuel briquette is spreading in Kenya’s urban and rural areas and the type of fuel briquettes produced depends on the locally available material. Astudy by Terra Nuova and AMREFKenya showed that sugar bagasse was used in Mumias, charcoal dust was used in Nairobi, coffee husks were used in Kiambu/Muranga, gum arabica was used in Isiolo, tree leaves were used in Machakos/Makueni, water hyacinth was used in Kisumu and rice husks were used in Mwea (Terra Nuova and Amref-Kenya, 2007).

To provide cooking energy from a range of sources to meet people's needs will require adequate, reliable and affordablesupplies,that result in minimal impact on the environment (Olz, 2007). In Kenya, production of fuel briquettes aims at supplying affordable, good quality cooking fuel, creating employment and income generation. To that end, fifty percent of briquette-making enterprises in the country are community-based organizations comprising of women and youth(Terra Nuova and AMREF-Kenya, 2007).Others involved in briquette production include non-governmental organizations and private companies. Most fuel briquette-making initiatives in Kenya are located in urban and peri-urban areas, with Nairobi hosting over half of them. The main raw material used in fuel briquette production by these urban based enterprises, is charcoal dust, which is bound with either biodegradable paper or soil.Charcoal dust as a main raw material in briquette production is popular in urban areas which could be associated to the high availability of charcoal dust following high use of charcoal among the poor and low income households. The other reason is that out of their trial on error practices, communities have found charcoal dust to yield a high quality product compared to other raw materials that they have tried to use such as maize comb and bean husks. And finally customers are more familiar with charcoal briquettes which looks and burns like wood charcoal. However due to challenges of accessing cooking fuel in rural areas other raw materials such as rice husks, rice straw, household organic waste are gaining popularity too.

The aim of this paper is to discuss the potential of charcoal briquette as an alternative cooking fuel based on research work carried out in Nairobi, Kenya. Charcoal briquette is a type of fuel briquette that is made from charcoal dust bonded with either paper or soil. It is the most commonly produced and used type of fuel briquette. The paper focuses on four aspects important for the utilization and sustainability of urban charcoal briquette production in developing countries. These aspects are (i) charcoalbriquette production methods adopted by community-based groups (ii) benefits for poverty alleviation, food security and the environment, (iii) charcoal briquette quality and (iv) policyissues.

4.2 METHODOLOGY

4.2.1 Study site

The study was conducted in Nairobi, Kenya, which is located in southern Kenya on 1^o 00" N and 30^o 00" E at an elevation of 1670m above sea level and covers an area of 700 square kilometres. The city's population is estimated at three million with an annual growth rate of2.8% between 2000-2015 and constitutes 23% of the country's population. Seventy five percent of the urban population growth is absorbed by informal settlements. Nairobi employs 25% of Kenyans and 43% of the country's urban workers. Sixty per cent of the city's population lives in low-income informal settlements and the numbers of urban poor projected to increase to 65 percent by 2015. (UN-Habitat 2006).The city generates 2000 tonnes of waste, only 40% of which is collected and disposed properly (ITDG-EA, 2003). Seventy percent of the waste is biodegradable. (JICA, 1997).Kibera is located within the legal city boundaries of Nairobi, approximately seven kilometre southwest of the city centre. It is one of the most densely populated informal settlements in the world, and Africa’s largest slum. It is not clear as to how many people live in this slum as the census of 1999 had the figure at close to one million while the 2009 census stands at 0.4 million within 2.5 square kilometres.

4.2.2 Surveys on production methods and use of briquettes by local communities

Firstly asurvey was conducted among seven community self-help groups (SHGs) in 2010. These charcoal briquette producing community SHG’s comprised all those identified and locatedusing an existing database on self-help groups involved in waste management in Nairobi (Njenga *et al*. 2010). A semi-structured questionnaire was administered to members of the groups through focus group discussions. These discussions were to document types, amounts and sources of raw materials and binders and production methods used in briquette making. Detailed procedures on fuel briquette production processes in Nairobi can be found in Njenga *et al*. in press). Secondly a survey was conducted among 199 households on use of charcoal briquettes. Fifty households were selected along four footpaths within a 250-metre radius of a charcoal briquette production site at Gatwekera village in the Kibera slums, in which every fifth household on those paths was interviewed.

4.2.3 Characterization of calorific value of charcoal briquettes

Charcoal briquettes were obtained during the focus group discussions (FGD) from seven of the eight identified community groups as one group did not have any samples at the time of the survey. Forty charcoal briquettes were randomly sampled from the pieces ready for sale from each group to determine relative proportion of charcoal dust (CD) to binding agents (%). The six types of briquettes collected include CD+Paper1 (3% wt), CD+Paper2 (7% wt), CD+Paper3 (26% wt), CD+Carton (46% wt), CD+Soil1 (20% wt), CD+Soil2 (34% wt). Each type of briquette listed originated from only one community SHG.

Charcoal briquettes samples were analysed using Infrared (IR) Spectroscopy following procedures described by Shepherd and Walsh (2007). In Near-infrared (NIR) and Mid-infrared (Mid-IR) the MPA Multi Purpose FT-NIR Analyzer and Tensor 27–HTS-XTBruker FTIR equipments were used respectively. A double sampling approach was used whereby a spectral library of the total 320 samples was first established and then a representative subset of 42 samples was selected based on the chemical and physical spectral diversity in the library(Shepherd and Walsh, 2007). These 42 samples were analysed for calorific value following procedures described by Findlay (1963). Calorific value is the heat released during combustion per mass unit of fuel (van Loo and Koppejan, 2009). As described by Shepherd and Walsh (2007) calibration based on the 42 samples were used to predict calorific value for the entire 320-sample spectral library.

4.2.4 Cooking tests

Cooking tests were carried out at the Human Needs Project (HNP) ground at Kibera slum in early 2012 to measure the amount of fuel and length of time taken to cook a meal for a standard household of five people. Six hundred and eighty grams of CD+Paper with 13% proportion of binder, 850 grams of CD+Soil with 20% proportion of binder, 890 grams of wood charcoal and 357 millitres of kerosene were used to cook a traditional meal. The traditional meal cooked is commonly known as G*itheri* which is amixture of 500 grams of green maize (*Zea mays*) and 500 grams of dry common bean (*Phaseolus vulgaris*).

4.2.5 Data management and analysis

Data was analysed using Microsoft Excel software for descriptive statistics such as mean and standard error. Microsoft Excel was also used to elicit the bar graphs and the box plot.

4.3 RESULTS AND DISCUSSIONS

4.3.1 Community groups and briquette production methods

4.3.1.1 Community groups and member profile involved in charcoal briquette production

The survey among the SHGsrevealed that the groups members came from the low income, high density neighbourhoods experiencing high unemployment and poverty. These are the neighbourhoods where charcoal consumption is high given that most households can seldom afford other types of cooking fuel such as LPG and kerosene. These neighbourhoods provide good market opportunities for the sale and use of charcoal briquettes which compliment charcoal as these two types of fuel use similar cook stoves.

The charcoal briquette-making groupscomprised of 68female and 101male with 78% of the members being youth below 35 years of age (F-45:M-89). The high level of youth involvement in charcoal briquette enterprises is one form of creating green jobs contributing towards sustainable cities. It helps address unemployment in Kenyan urban areas that is estimated at 18%, (F-24%:M-14%) (MoPND, 2003).

Of the survey respondents, 39% had a primary education(F-50%:M-50%), 46% had a secondary education (F-35%:M-65%) and 15% had some tertiary education (F-28%: M-72%) an indication of high literacy level in the enterprise (Table 4.1). There were many females with primary education but very few of them had above secondary school education and hence trainings should be designed in a away that they suit their level of education.

Table 4.1: Education level and gender composition of group members producing charcoal briquettes

Community groups	No formal education		Primary		Secondary		College		University		Total
Gender of members	M	F	M	F	M	F	M	F	M	F	
Nyooni self-help group					11						11
Soweto youth in action			2	1	7	2	7	2			21
Vijana youth cleaners			1		6		7	2		1	17
City garbage recyclers				1	5						6
Kayole environmental management association			30	5	21	23	3	2	1		85
Tujikaze women group		1		26		1					28
New beginning sympathy women group						1					1
Total		**1**	**33**	**33**	**50**	**27**	**17**	**6**	**1**	**1**	**169**

Of the community group members, 87% were directly involvedin charcoal briquette production activities while the rest were students (3%)or involved in other group activities such as garbage collection (6%) and compost production (1%) and a few operated their own small bunisesses (2%) or were in formal employment (2%). The group members directly involved in charcoal briquette production allocated less than 30% of their time to this activity and this time was mainly during their free time. These group members were also involved in other income generating activities such as other small businesses, rural and urban agriculture, casual labour and formal employment, in that order. The SHG produced between 5,760 and 336,000 pieces of charcoal briquettes per year as shown in table 4.2.

Table 4.2: Annual charcoal briquette production capacity by the SHG's

Community groups	Pieces produced per day	Number of days worked in a month	Pieces produced per year	Weight per piece (grams)	Total production per year (kilograms)
Nyooni self-help group	450	12	64800	280	18144
Soweto youth in action	600	12	57000	230	13110
Vijana youth cleaners	100	12	14400	250	3600
City garbage recyclers	60	8	5760	430	2477
Kayole environmental management association	12000	20	288000	330	95040
Tujikaze women group	5600	5	336000	920	309120
New beginning sympathy women group	250	8	24000	100	2400

SHGs play a great role in addressing cooking-energy poverty where they comprise 50% of fuel briquetting enterprises (Terra Nuova and AMREF-Kenya, 2007). The SHGs come together to generate income, create employment opportunities, and source cooking energy. Further, they also clean their neighbourhoods that are faced with waste management challenges as only 40% of waste generated in the city is collected and disposed of. Fuel briquetting contributes to the informal economy which is known to involve people in the slum more than non-slum dwellers (UN-Habitat, 2010). The SHG's have been producing charcoal briquette since the early 90's which was noted among two of them while the rest five started the enterprise in the early 2000.A study on groups involved in organic waste management in Nairobi showed similar objectives of members of the community coming together in poor neighbourhoods to address their livelihood and environmental challenges (Njenga *et al*. 2010).

4.3.1.2 Charcoal briquette production methods adopted by the community groups

The study among SHG's involved in fuel briquette production established that charcoal dust bonded with paper, or soilwere the main raw materials used in briquette production in Nairobi. The main sources of charcoal dust was charcoal retailing stalls for six groups, while one group sourced it from dumping sites. The groups that sourced charcoal dust from charcoal retailing stalls bought it at US$0.02 per kilogram. Waste paper was sourced from either newspaper vendors, schools or dumping sites. The group that collected paper from dumpsites and those that obtained paper from schools got it for free. Only one group sourced paper from newspaper vendors and bought at US$0.4 per kilogram. Soil was collected for free from river banks or road reserves. And water was purchased for US$0.02 per litre from water vendors or kiosks or sourced from shallow wells.

The organic biomass and binders were hand sorted to remove impurities such as pieces of wood, metal and plastics. Charcoal dust was sieved through recycled nylon 5 mm nets to separate the fine dust from bigger particles which were later mixed at a ratio of 1:1. Paper was shredded manually then soaked in water for about 2-3 hours before mixing with charcoal dust. To test for consitency and stability of the mixture, the slurry was squeezed in one hand and then held between the thump and the index finger and if it fell apart, binder was added until it held together. The mixed slurry was pressed to compact it into solid blocks of different shapes and sizes and squeeze out the water using methods shown in Figure4.1.

Figure 4.1.Pressing fuel briquettes using (a) wooden manual press (b) metal manualpress and(c) molding in recycled plastic container

Charcoal briquettes were dried either in the sun or under shade. During the dry season they took about eight days to dry while during the wet season they took 11 days. The production methods applied by the groups indicate a large potential of its application in different regions where the raw materials depend on locally available biomass material. For instance rice husk is bonded with rice bran and maize cob is bonded with molassesin China and Thailand respectively (Chou, 2009; Wilaipon, 2007).

4.3.2 Socio-economic aspects and adequacy of briquettes as fuel

4.3.2.1 Income and factors influencing use of charcoal briquettes

Monthly incomes from sales of charcoal briquettes by the community groups varied between US$7-$1771 during the dry seasons and US$7-$2240 during the wet seasons.Charcoal briquettes were traded in pieces of between 100 to 920 grams each and the prices were different among the groups. Tujikaze women group from Kibera had the lowest price but realised the highest income due to high volumes traded. The main customers include households, food kiosks, institutions such as schools and chicken hatcheries. As illustrated in Figure 4.2a, 70% of the 199 interviewed households living within 250m radius of a briquette production site in Kibera used charcoal briquettes. Most of those who produced and used charcoal briquettes were from the very poor households in the low income bracket with annual earnings ranging from USD128 to 960 per year. There were more producers who made charcoal briquettes for both home use and sale than those who produced for home use only implying that this activity is both for sustenance and commercial.

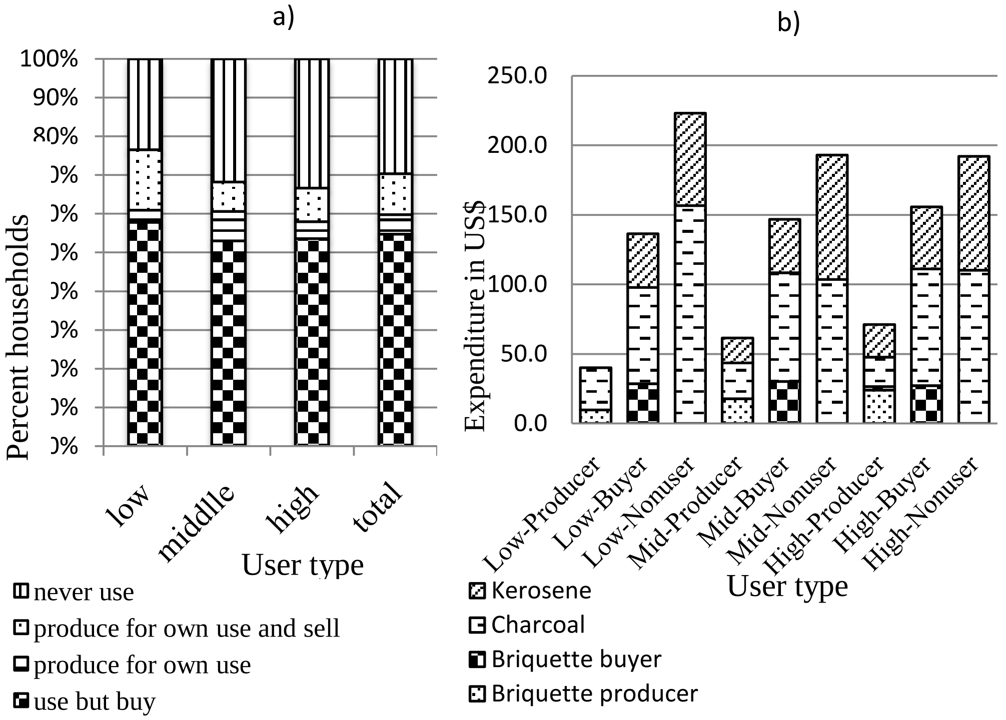

Figure 4.2.(a) Utilization of charcoal briquettes and (b) annual expenses on cooking fuel by the residents of Kibera slums ordered by the different income groups.

Low=low income (US$128-960), mid=middle income (US$961-1921), high = high income (US$1921-7200). Producer and buyer used charcoal briquettes; nonuser did not use charcoal briquettes.

Households that produced briquettes for home use made savings of over 70% while for those who purchased saved 30%. The highest savings was 82% noted among the low income households that produced charcoal briquettes as they spent US$40 per year on cooking fuel compared to US$223, spent by their counterpart households that did not use charcoal briquettes.The high level of saving by these low income households is due to charcoal briquette production being cheaper than buying briquettes while further savings are generated by the non-use of kerosene. The income that women generated through selling briquettes or saved through use of briquettes was spent on other livelihood needs such as food, health, school fees and paying rent. The household survey in Kibera revealed that briquette producers were all women majority of who did not belong to Tujikaza women group that was involved in the focus group discussions. This indicative the role they often play in sourcing cooking energy. Dependence on wood charcoal was highest among the poorest households who have the most limited resources that could be used to procure other types of cooking energy like kerosene.

The study involved households within 250-metres radius from the charcoal briquette production site and hence the high use of charcoal briquettes in the studied village may have been influenced by the nearness to the source resulting into high awareness of the product. Other factors that may have contributed to use of charcoal briquettes include family size where for instance charcoal briquette producing households had more people (Table 4.3).The increased need of poorer households to live within tight financial budgetsis accomplished through production and use of charcoal briquettes, as opposed to consuming other fuels. More female-headed households producedcharcoal briquette for home use hence contribution of gender in adoption of this alternative fuel. On the other hand education level of household head also contributed to involvement in productionof charcoal briquettes which could be associated to higher awareness and ability to gather information on one’s own benefit.Education was found to play a role in adoption of improved farming technologies in Nigeria as found by Odoemenen and Obinne (2010).

Table 4.3. Characteristics of interviewed household in Kibera slum

	Producer				Buyer				Non-user				Total
	L	M	H	Avg	L	M	H	Avg	L	M	H	Avg	Avg
N	12	10	9		37	35	37		15	21	23		
HH size (persons)	6.8	5.9	7.3	6.7	5.3	5.6	5.4	5.4	5.5	4.1	4.5	4.7	5.4
Age of HHH	38.4	34.3	36.9	36.5	32.2	33.3	34.8	33.4	32.2	30.5	32.6	31.8	33.4
Female headed HH (%)	25	20	22	22	22	11	8	14	33	5	13	17	16
HHH completed secondary school (%)	42	20	22	28	27	17	24	23	13	29	26	23	24
Annual income (US$)	516	1296	2808	1540	566	1400	2733	1566	539	1336	2698	1524	1576

N= number of households, HH=Household, HHH=Household head, L=low, M=middle, H=High, Avg=Average, Exchange rate US$1=Ksh75

Charcoal briquettes have various characteristics that contribute to their preference for household cooking. All the 140 households that used charcoal briquettes in Kibera preferred them to charcoal due to their lower price. Nearly unanimously, 98% of households stated that charcoal briquettes burn for a longer period of time than charcoal. This time advantage makes briquettes suitable for preparing foods that require a longer time to cook such as dry grains, foods which many households are currently abandoning due to the high costs of other fuels (Figure 4.3).

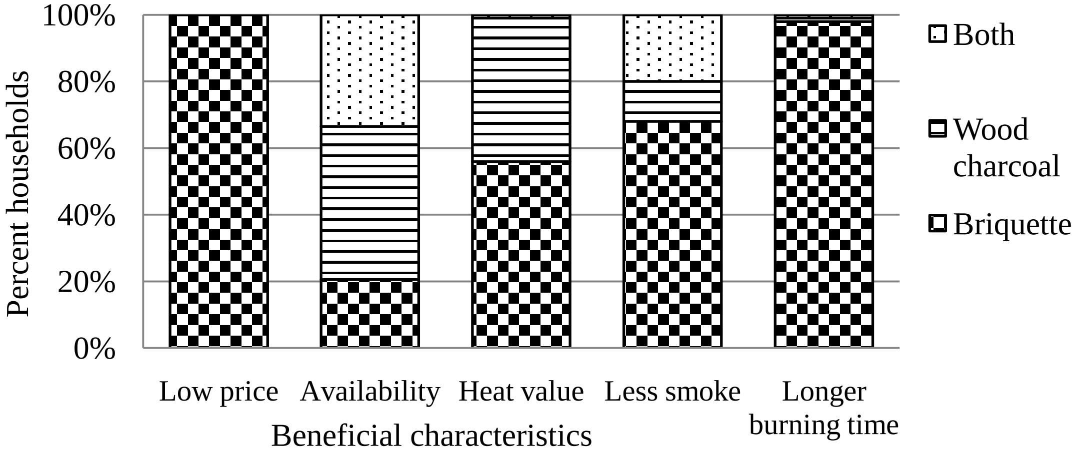

Figure 4.3. Consumer preferences of charcoal briquettes compared to wood charcoal

Production of less smoke by charcoal briquettes was one of the characteristics that contribute to their preference. Observations during the cooking tests showed that charcoal briquettes forms no soot on pots after cooking hence user friendly to a community with limited access to clean water and living space. The observations by the users were confirmed by analyses showing that these briquettes gave lower indoor air emissions of carbon monoxide (CO) and fine particulate matter ($PM_{2.5}$) compared to charcoal, when used in cooking stoves(Njenga *et al.* in press). The same analysis showed that charcoal briquettes had lower emissions of CO and $PM_{2.5}$ than fuel briquettes made from sawdust bonded with gum arabica resin (Njenga *et al.* in press)

4.3.2.2 Charcoal briquettes contribution to food security and saving of trees

Cooking-energy poverty is one of the main challenges faced by poor households in their efforts to feed their families. Charcoal briquettes, in addition to being cheap and available within the neighbourhoods, can also contribute to food security. This possible security is evidenced by cooking tests that showed that, the 88 tonnes of charcoal dust produced in Nairobi daily could be used instead to produce CD+Soil (20% binder) briquettesthat could cook 129,000 traditional meals of a mixture of green maize (*Zea mays*) and dry common bean (*Phaseolus vulgaris*) commonly known as G*itheri*. Consequently, in a year,charcoal briquettes could result in cooking about 45 million meals from recovering the charcoal dust produced in the city. The cooking tests showed that each meal takes178 minutes, 168 minutes and 166 minutes to cook with charcoal briquette, charcoal and kerosene respectively. This projection assumes aKenyan standard householdof five people.

Cooking the meal with charcoal briquettes costs 3ksh (US$0.04 – 850 grams) with charcoal costs 26 ksh (US$0.35 - 890grams of charcoal) and with kerosene, 45 ksh (US$0.6 - 0.36 litres of kerosene). Cooking the meal with charcoal briquettes thus costs 88% and 93% less than cooking the meal with charcoal and keroserespectively.This would benefit poor households who comprise 60% of the city's population. Recovering the dust that would otherwise get burned could result in the production an extra over 15% cooking energy hence saving similar amount of trees that would be cut for charcoal. (Njenga *et al*. unpublished data). These findings are timely as there is an expected increase in bioenergy use that calls for identification of conditions under which bioenergy systems can be implemented sustainably (Hecht *et al*. 2009). Sustainability of bioenergy should be addressed both at large regions and local sites and should apply to diverse stakeholders (McBride *et. al*., 2011). In this case community groups are playing a pivotal role in the development of cooking energy that supports environmental sustainability.

4.3.3 Charcoal briquette quality

4.3.3.1 Calorific value

Calorific value of the SHGs briquettes ranged between 13.5kJ/g and 21.4kJ/g (Figure 4.4.). The highest calorific value was recorded in CD+Paper3 while the lowest was in CD+Soil2 (Figure 4.4).While paper as a binder elevated the calorific value of the briquettes, soil had a negative influence. The negative influnce of soil on calorific value is because soil is non-combustible (van Loo andKoppejan, 2009). Results of this study agrees with results in previous studies that showed type of raw materials and proportions used influnce calorific value (Chou*et al*. 2009).As such there is need for further research to develop standards and guidelines for fuel briquette quality control .

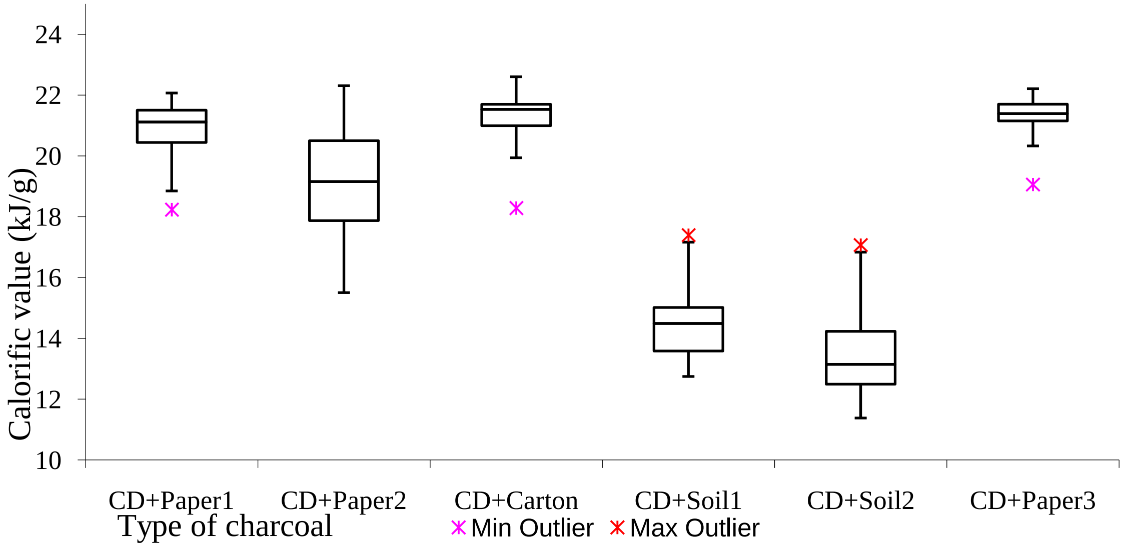

Figure 4.4. Box plot on calorific value of briquettes produced by self-help groups

Briquettes are a good source of cooking fuel and compare well with the conventional wood charcoal with a 25.3 kJ/g calorific value and firewood 13.7 kJ/g (Fuwape, 1983). Charcoal briquettes in our studyhad calorific values exceeding 14.1kJ/g, which was obtained in maize cob briquettes in Thailand (Wilaipon, 2007).Charcoal briquettes had higher calorific value than that made from sawdust bonded with gum Arabica except where soil was used as a binder (Njenga *et al*., in press). Results presented in the box plot in Figure 4.3 indicate that the production methods applied to produce CD+Paper1,CD+Carton and CD+Paper3 yielded a product with consistence in calorific value among the analysed samples. The other groups produced a product that had large variationin calorific value among the analysed samples. This information shows the need for technical capacity building of SHGs so that they can produce a product whose quality is known and consistent.

4.3.4 Policy relevance of charcoal briquette

Charcoal briquette production and marketing provide a strategy that contributes to a supply of an affordable source of cooking energy for the poor with the further benefits of contributing to poverty alleviation, food security and environmental management. The enterprise generates income through sales mainly for youth and women involved in production. Charcoal briquette production is carried out by poor communities who have a comparative advantage in local markets as they are located in informal settlements, and consequently benefit from local supply and distribution. The prospects for charcoal briquettes in Kenya is high due to the increasing costs in cooking fuel such as kerosene, liquid petroleum gas and charcoal coupled with increasing rates of urbanization, poverty, food and nutrition insecurity and poor waste management services. The motivation of self-help groups to produce more charcoal briquette depends on the demand from customers and as demand is rising which consequently will mean more income these activity is likely grow. This activity integrates well with other household chores which most SHG members carry out during their free time and is spreading fast in both urban and rural areas. Various options are discussed below on how to raise the capacity of the SHG’s in sustainable charcoal briquette production.

Briquette production improves access of the urban poor to cheap, clean cooking energy that contributes to saving income that is made available for other uses such as food, health and education. Use ofcharcoal briquettes leaves no soot on cooking pots, reducing consumption of household water for cleaning, as water is a resource that is expensive, insufficient and obtained with a lot of effort in poor neighbourhoods. This water savings is in line with lower water consumption as an indicator of sustainability of biomass energy (McBride *et. al*., 2011).

Unfortunately, slum areas remain generally ignored when it comes to policy interventions, job creation and gender support (UN-Habitat, 2010). For these SHGs to prosper and make full impact, local authorities need to provide assistance to these kinds of small enterprises, enabling them to better access resources such as space under lease agreement. This assistance will encourage communities to construct appropriate infrastructure such as beds for drying and selling, as well as stores.Water also needs to be provided at a reasonable cost to these communities. This water access must be aligned to urban planning so as to recognize charcoal briquette production as a productive sector. Although provision of these production servicesmight cause an extra cost in the charcoal briquette enterprises it would help expose briquette producers to potential buyers.

Fuel briquette production needs to also be linked to waste management in which the local authorities can help link the local fuel briquette-producing communities to government institutions, such as schools, for sourcing of paper. In waste managementaiming at decentralised reuse and recycling of waste, charcoal briquette making would be a way to reduce the need for transporting waste out of residential areas by separating and reusing waste close to the source. Waste management stakeholders should facilitate the development of partnerships between local charcoal traders and charcoal briquette producers so that the latter can directly source charcoal dust from the former as opposed to sourcing from dumpsites which has been noted to cause heavy metal contamination (Njenga *et al.*in press).The 10-15% waste generated along charcoal supply chain in our urban areas can ensure continued charcoal briquette production if the above concerns are addressed. This trend will follow the foreseen dependence of charcoal use in African cities though sustainable tree production is needed as discussed later in this section. However given the benefits of charcoal briquettes as a cheap and environmental friendly cooking energy option, chances are that communities might shift to grinding charcoal for charcoal briquette production and as such there is need for further studies to evaluate the financial and environmental implications of such an undertaking. On the other hand to meet the increasing demand for charcoal briquette there is need to evaluate potential in using other raw materials such as carbonizing the over 230,000 tonnes of sawdust generated annually by Kenya's sawmill industry adding to the unknown amount of existing sawdust mountains across the country, most of which is burned at the site. Carbonizing sawdust before making fuel briquettes is crucial as Njenga *et al*., (in press) showed risks of high fine particulate matter from burning fuel briquettes made from fresh sawdust.

Briquette can play a role in the social inclusion of unemployed youth and women by providing them an opportunity to raise their income, participate in the cleaning of urban neighbourhoods and the conservation of tree and forest cover. Women bear the load of bringing food to the table for SSA families and it is frustrating if they have food but it cannot be cooked due to lack of fuel.

The Ministry of Energy has mandate to provide adequate energy sources in Kenya. Environmental Management and Coordination Act 1999, paragraph 49, specifies that the

Act promotes use of renewable energy sources and charcoal briquettesare one such source. The growing attention by the government on biomass energy is stipulated in The Sessional Paper No. 4. of 2009 on Energy in section 2.4.7 which outlines the importance of recycling municipal and industrial waste for energy. Section 6.3.1 emphasizes the government's support of use and development of efficient cook stoves that if adopted,will elevate the benefits of charcoal briquette burning slowly with less smoke. The paper also supports research and development on alternative sources of energy as well as improvement on efficiency. There is need for implementation of the above policy statements so that briquette technology can be developed in the country.

Development of social-economic-environmental friendly cooking-fuel policies in the country should integrate fuel briquetting as a viable option. There is progress in this aspect as the proposed national biofuel policy in the section on biomass technology, promotes the use of crop and wood residues for energy (MoE, 2009). Community-based self- help groups need to be involved in the government planning process for cooking energy.

Various organizations have been involved in fuel briquette production such as the sugar factories, the Coffee Planters Cooperative Union (KPCU) through recycling their agricultural residues. Chardust Ltd produces charcoal briquettes from charcoal dust sourced from slums of Nairobi. Faced with growing cooking energy needs, fuel briquettes research and development focusare receiving increased recognition by organization such as the Kenya Forest Research Institution (KEFRI), Kenya Industrial

Research and Development Institute, Universities, International Research Centres, Development Practitioners and donors. Collaboration would be beneficial amongst stakeholders to share lessons and scale out ‘best practices’as well as assisting community groups with technical skills. One way to achieve the collaboration for scaling-out fuel briquette production would be to use the existing institutional relationships organized by the Ministry of Energy that has 10 energy centres located in different parts of the country. Another channel would be through bringing together several SHGs for participatory training. For training to be effective, there is the need for stakeholders to collaborate in development of user guidelines and delivery of the participatory training. The training should be gender responsive both in content and modes of delivery.

Technical capacity-building is needed among charcoal briquette producers to enable production of a quality product which is consistentenough to effectively compete with conventional charcoal. Government and other organizations need to increase financial and other types of support for research on and development of fuel briquettes to address cooking energy demands while being sensitive to concurrent public health and climate change issues. For example, although charcoal briquette produces less smoke than charcoal, there is need to link its use to development of efficient cook stoves and public health education on indoor air pollution. Another area that requires financial support is awareness-raising on fuel briquettes as an alternative cooking fuel through numerous media, learning institutions and other social gatherings. For sustainable charcoal briquette production in the country there is need for adoption of more efficient wood carbonization processes as opposed to using the traditional methods with efficiency of

10-20% in yieldcurrently being used by 99% of charcoal producers leading to immense wood wastage (Mutimba and Barasa, 2005; Okello, 2001).

All households in informal settlements as found in the study at Kibera, use charcoal which fuel briquettes are substituting as the two types of cooking fuel use similar cook stoves. This substitution withcharcoalbriquettes contributes to saving trees, which is important as the country struggles to move from less than 2% of forest cover to the recommended 10%. Saving trees has multiple benefits such as better management of water catchments, mitigating climate change as trees serve as carbon dioxide sinks, and conservation of biodiversity. Charcoal briquettes produce less emissions which is a positive indicator in addressing indoor air pollution which has been known to cause over 1.6 million annual deaths globally, 400,000 occurring in SSA (Ezzati, *et al*. 2002).Promotion of charcoal briquette use should be combined with use of efficient cook stoves where for intance use of imporved Kenya Ceramic Jiko (KCJ) reduced emission of CO by 15% (Kituyi, 2001).

In juxtaposition, if charcoal dust is unrecovered, it poses a disposal problem and it is either dumped in open drains, polluting and clogging up the system, or burned, causing air pollution especially in the informal settlements in urban areas. Because charcoal dust is the main raw material for fuel briquette production in the country, the production process should be linked to research on and development of tree farming through short rotations for charcoal production. The charcoal briquette productionshould also be integrated in management of forests and tree resources through working with local communities as those in areas neighboring forests. Working with Community Forest Associations (CFAs) would be one way to reach these communities.

4.4. CONCLUSIONS AND RECOMMENDATIONS

Charcoal briquette production is a technology that helps poor urban dwellers, especially women and youth, with important employment and incomeopportunities. Charcoal dust briquettes provide affordable and good quality cooking energy for households in poor neighbourhoods. Technical capacity building in local communities through partnerships is necessary so as to improve on quality consistence. Charcoal dust briquettes have environmental benefits that include reduced tree degradation, better management of waste and reduced emissions. There is need to link charcoal briquette production to sustainable charcoal production such as short rotational agoforestry. Energy and waste managementpolicy initiatives should include recovery of organic by-products for charcoal briquette production.

4.5 ACKNOWLEDGEMENT

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CHAPTER 5: QUALITY OF COOKING FUEL BRIQUETTES PRODUCED LOCALLY FROM CHARCOAL DUST AND SAWDUST IN KENYA

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ABSTRACT

Fuel briquettes are made by compressing biomass material into a uniform solid and present an opportunity for good quality cooking fuel. The study evaluated the quality of locally produced fuel briquettes in Kenya and their combustion properties, chemical composition and emissions of gases and fine particulate matter. Briquette made from charcoal dust bonded with paper, soil or corn starch and sawdust briquettes bonded with gum arabica were studied. Charcoal dust briquettes bonded with corn starch or paper had the highest calorific values of 23.6kJ/g and 21.4kJ/g respectively. Contaminants comprising of chromium, mercury and lead were high in briquettes made from material sourced from garbage heaps in informal settlements and dumpsites. Charcoal dust briquettes bonded with soil was the safest in terms of indoor air concentrations of carbon monoxide and fine particulate matter when burned. Burning sawdust briquettes bonded with gum arabica caused the release of high concentrations of fine particulate matter. When briquettes intended as cooking fuel are produced, the effect of raw materials should be taken into account.

Key words: community groups; briquette; cooking fuel; calorific value; indoor air pollution

5.1 INTRODUCTION

Growing energy demands is one of the major challenges facing the world today. About 2.4 billion people use solid biomass fuels as a source of energy for cooking and heating[1]. In sub-Saharan Africa over 72% of urban and 98% of rural households use fuelwood for energy[2]. Charcoal is the principal fuel for the urban poor in Kenya[3] which provides energy for 82% of urban and 34% of rural households. The per capita consumption is about150kg with an annual national consumption of 1.6 to 2.4 million tonnes[4]. The poor populations who are the majority users of wood charcoal cannot afford to use electricity and/or Liquid Petroleum Gas (LPG) for cooking because of the high costs of fuel and cooking appliances[5]. Sixty percent of Kenya's population lives in low-income informal settlements and the numbers of urban poor is projected to increase to 65 percent by 2015[6].

About 10-15% of charcoal is wasted along the supply chain as charcoal dust found as waste at the retailing and whole sale stalls. The charcoal dust poses a disposal problem and it is either dumped in open drainage systems clogging the system or burned causing air pollution. Kenya's sawmill industry generates up to 230,000 tonnes of sawdust annually adding to the unknown amount of existing sawdust mountains across the country, most of which is burned at the site. The biomass residues generated by the wood-based industry in most developing countries have potential to replace energy sources such as firewood in domestic energy needs such as demonstrated in Cuba, Nigeria, Brazil, China, Kenya[7-11]. However, only a small proportion of the residues are used as fuel because of their high moisture and low energy density. These characteristics are known to increase costs of transport, handling and storage, making the use of biomass fuel expensive[12]. Some of these drawbacks could be overcome through densification of biomass residues into briquettes.

Briquettes are made by compressing biomass material such as charcoal dust, sawdust and other wood residues or agricultural by-products into a uniform solid unit [8, 9]. Briquetting of biomass is done using various techniques, either with or without binder addition. For biomass material that lacks plasticity, addition of a sticking or agglomerating material, preferably combustible, is required to enable the formation of solid briquettes[9]. Common binders are starch, gum arabica, soil, animal dung or waste paper.

Biomass briquettes are mostly used for cooking, heating, barbequing and camping in countries such as the United States of America , Australia, Japan, Korea and Taiwan and countries in the Eureopean Union. In developing countries, biomass briquettes are mainly for domestic usage[13]. In the Kenyan situation, like in many developing countries, briquette production is focused on providing good quality cooking fuel. It is therefore important to understand the effects of various types and amounts of raw material and binder on briquette quality. Amount of starch or gum arabica used in binding sawdust affected the calorific value of the briquette[13]. As some briquettes are produced using raw materials collected from dumping sites, heavy metal contamination is an important aspect to be characterized. Heavy metals are important to study in biomass fuel due to their non-degradable nature leading to bioaccumulation which may have negative biological effects[14]. Even at low concentrations, elements such as chromium (Cr) and lead (Pb) are harmful to plants and humans[15].

Carbon monoxide (CO) and particulate matter (PM) are the major pollutants released from incomplete combustion of solid fuels used by households[16]. These pollutants contribute to over 1.6 million annual deaths globally, of which 400 000 occur in sub-Saharan Africa (SSA)[2]. There is a need to link knowledge on briquette quality and raw material characteristics to indoor air concentration of carbon monoxide, particulate matter and carbon dioxide (CO_2). This is useful for understanding the local and global environmental and health effects of briquette use. In 1995, it was estimated that 28 Tg(Teragrams)C yr^{-1} of CO were annually emitted in Africa from domestic biomass combustion and its mean atmospheric residence time has been estimated to be five years[17].

To contribute to development of viable options for biomass cooking fuel in Kenya, this research is aimed at evaluating local production of briquette and the quality of the product. The briquettes studied were produced by seven local community groups and one private company, and were made from charcoal dust bonded with paper, soil or corn starch and those made from sawdust bonded with gum arabica. The research involved characterizing combustion properties including ash content, calorific value and volatile matter. Concentrations of chemical elements in briquettes were also measured. The study also assessed the indoor air concentrations of carbon monoxide (CO), particles smaller than 2.5 µm referred to as fine particulate matter ($PM_{2.5}$) and carbon dioxide (CO_2) from burning briquettes in a situation simulating a kitchen[18].

5.2 MATERIALS AND METHODS

5.2.1 Study area

The studywas conducted in Nairobi city which is located in southern Kenya on 1^{o} 00" N and 30^{o} 00" E at an elevation of 1670m above sea level and covers an area of 700 square kilometres. The city's population was estimated at three million in 2009 census. Six of the groups studied and the private company were based in Nairobi while one group was located in Naro Moru town, 150 kilometres North East of Nairobi.

5.2.2 Briquette production

A diagnostic study was conducted using a semi-structured questionnaire to document the types, amounts and sources of raw materials and binders and production methods used in briquette making. Briquette production methods adopted by seven community based groups and one private company were studied. To identify and locate briquette producing groups, an existing database on community groups involved in waste management in Nairobi was used[19]. Figure 5.1 presents the briquette production methods illustrating raw materials, binders, pressing methods, briquette produced and proportion of binders by weight. The community groups use different (Figure 5.1.) locally developed methods for pressing briquettes and data on specific pressure are therefore unavailable.

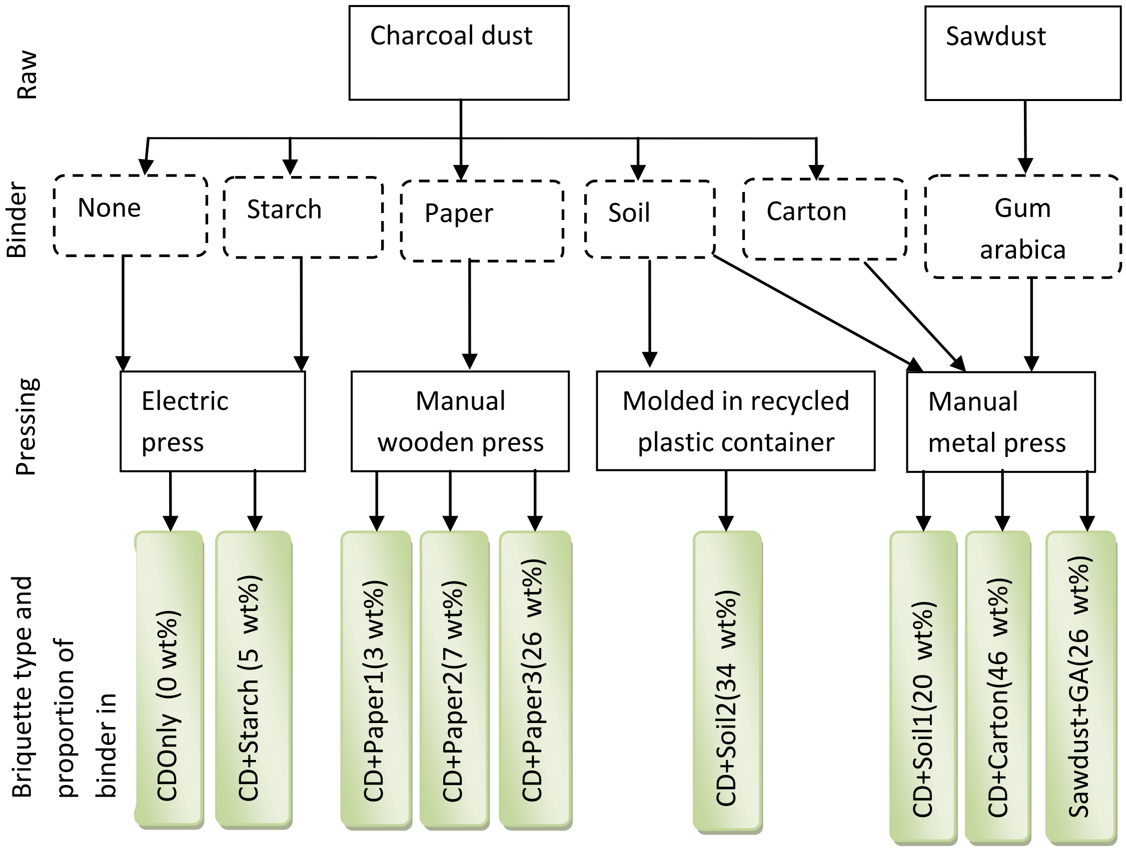

Figure 5.1 Briquette production methods in Kenya. CD=Charcoal dust and GA=Gum arabica

The sources of raw materials and binders are presented in Table 5.1. Charcoal dust was bought at US$0.02 per kilogram while sawdust cost US$0.01per kilogram. The groups that collected paper from dumpsites and schools collected it for free while the group that used paper sourced from newspaper vendors bought it at US$0.4 per kilogram and soil was free. The groups used tap water that was bought at US$0.02 per litre except for production of CD+Soil2, CDOnly and CD+Starch where water was sourced free from shallow wells.

Table 5.1.Sources of raw materials and binders

Briquette type	Source of raw material[1]	Source of binder
CD+Only	[2]CDStalls in Kibera	None
CD+Paper1	CDStalls at Uthiru	Newspapers vendors
CD+Paper2	CDStallsKahawa Soweto	Schools
CD+Paper3	CDStalls at Kangemi	Schools
CD+Carton	Dumping sites at Maringo	Dumping sites at Maringo
CD+Soil1	CDStalls at Kayole	Road sides
CD+Soil2	CDStalls in Kibera	River banks
CD+Starch	CDStalls in Kibera	No information
Sawdust+GA	Timber/wood mills in Naru Moro town	Dry lands as a residue during grading for sale

[1]Kibera, Kahawa Soweto, and Kangemi are informal settlements while Uthiru, Maringo and Kayole are low income areas. [2]CDStalls=Charcoal dust retail stalls

5.2.3 Raw material preparation and processing

The raw materials and binders were sorted to remove impurities such as pieces of wood, metal and plastic. Charcoal dust was then sieved through recycled nylon nets with about 5 mm holes to separate the fine dust from larger particles. The larger particles and fine dust were later mixed at a ratio of 1:1. This was carried out to produce briquette types CD+Paper1, CD+Paper2, CD+Paper3 and CD+Carton. Fine dust was used in production of briquette types CD+Soil1, CD+Soil2, CDOnly and CD+Starch. Paper was shredded into small pieces using hands by all groups except the group that produced briquette type

CD+Paper1where a hand operated shredder was used. The shredded paper was soaked in water for 2 to 3 hours while gum arabica was soaked in water overnight. The prepared raw materials and binders were mixed in the ratios shown in Fig. 1. To test if the mixed slurry bonded well, the slurry was squeezed in one hand and then held between two fingers and if it fell apart, more binder was added until it held together.

The mixed slurry was pressed to compact it into solid blocks of different shapes and sizes and squeeze out the water using methods shown in Figure 5. 1. Wood charcoal samples of unknown source collected from a trader at Uthiru were used as a control in this study.

5.2.4 Determination of combustion properties of briquettes

The combustion properties include ash content, calorific value and volatile matter. Forty samples of each type shown in Table 1 and wood charcoal were analysed using Infrared (IR) Spectroscopy following procedures described by Shepherd and Walsh [20]. In Near-infrared (NIR) and Mid-infrared (Mid-IR) the MPA Multi Purpose FT-NIR Analyzerand Tensor 27–HTS-XTBruker FTIR equipments were used respectively. A double sampling approach was used where by a spectral library of the total 400 samples was first established and then a representative subset of 50 samples was selected based on the chemical and physical spectral diversity in the library[20]. These 50 samples were analysed for mositure content, ash content, calorific value and volatile matter following procedures described by Findlay[21]. Volatile matter was measured using 0.5g of the sample which was heated in a furnace at 800 ^{o}C for five minutes. Volatile matter was then expressed as the percentage of loss of weight of the original sample. The ash content was determined the same way as volatile matter but this time the sample was heated for 1.5 to 2 hours.

Calibration based on the 50 samples were used to predict combustion properties for the entire 400-sample spectral library as described by Shepherd and Walsh[20].

5.2.5 Determination of chemical elements in briquettes

The subset of 50 samples were analysed for multiple elements using the S2 PICOFOX^{TM} (Bruker AXS Microanalysis GmbH) total x-ray fluorescence (TXRF) spectrometer. Each sample was milled to <50 µm using a micronising mill (McCrone, Westmont, U.S.A.) and amount of 45 mg of each finely ground sample was mixed with 2.5 ml of Triton X-100 (Fischer Scientific, UK) solution (0.1 vol.-%) to form a suspension and then spiked with 40 µl of 1000 mg l^{-1} Selenium (Fluka Analytical, Germany) as the internal standard. Triton®-X 100, an organic compound, applied for TXRF sample preparation, enhances the homogeneity of samples[22].The solution was then mixed well using a digital shaker and 10 µl of the solution immediately dispensed on to a clean siliconized quartz glass sample carrier and dried on a hot plate set at 40 ^{0}C for 5-10 minutes. Sample analysis time was about 10 minutes per sample while the data acquisition time was set at 1000 s per sample. The interpretation of the TXRF spectra and data evaluation was performed using the software program SPECTRA 6.3 released by Bruker and included with the S2 PICOFOX spectrometer.

5.2.6. Measuring concentrations of carbon monoxide, fine particulate matter and carbon dioxide from burning briquettes

The concentration of CO, fine PM $_{2.5}$ and CO_2 were measured from burning an amount of fuel that filled the small-sized energy saving cook stove called Kenya Ceramic Jiko

(KCJ) as practiced by households: 650 grams of CD+Paper1, 565 grams of CD+Carton, 750 grams of CD+Soil2, 1000grams of CD+Starch and 450 of Sawdust+GA briquettes and 640grams of wood charcoal. These briquette types were selected to represent main raw materials and binders. Water was heated in an aluminium cooking pot, 2.5 (CD+Paper1, CD+Carton, CD+Soil2, and Sawdust+GAbriquettes) or 3.2 liters (CD+Starch and wood charcoal). Trials showed that the latter two types of fuel made water reach boiling point and hence more water was needed. Measurements were carried out in triplicates in a kitchen measuring 3 by 3 metres with one door and two windows simulating household cooking conditions. Measurements were taken throughout the burning period of each type of briquette which were 210 minutes for CD+Paper1, 210 minutes for CD+Carton, 240 minutes for CD+Soil2, 210 minutes for CD+Starch,60 minutes for Sawdust+GA and 150 minutes for wood charcoal. The measuring equipments were hanged with a rope one metre high aboveand to the side ofthe cooking pot and stove, simulating the height of a person cooking. Carbon monoxide was measured at 10 seconds intervals using EL-USB-CO carbon monoxide data logger, DATAQ Instruments. Fine particulate matter measurements were taken per minute using a particulate matter meter, UCB, Berkeley Air Monitoring Group. Carbon dioxide was measured at intervals of 5 minutes using Taile 7001 Carbon Dioxide and Temperature, LASCAR.

5.2.7 Data management and analysis

Data was analysed using Microsoft Excel software for descriptive statistics such as mean and standard error. Genstart Edition 13 was used for One Way Analysis of Variance (ANOVA) [23]. ANOVA was carried out to test significant difference between the means of different types of briquettes. Significance difference between any two means was tested using the least significant difference of means (LSD) from the ANOVA results.Actual probability values have been presented as 'p' to show significance at confidence level of 95%. R^2 indicates coefficient of determination as a measure of the degree of linear association between two variables. R^2 may take on any value between 0 and 1.

5.3. RESULTS AND DISCUSSION

5.3.1 Combustion properties of briquettes

Ash content in briquettes ranged between 4.4% to 34% and sawdust+GA had the lowest while CD+Soil2 had the highest values (Table 5.2).

Table5.2. Mean values of ash content, calorific value and volatile matter.

All values are expressed as % of dry weight. Least significant difference (LSD) values are given at 95% confidence level.

Treatment	Ash	Calorific value (kJ/g)	Volatile matter
CD[1]Only	22.8±0.3	19.9±0.1	20.3±0.2
CD+Paper1	18.4±0.5	20.8±0.2	20.1±0.3
CD+Paper2	25.4±0.9	18.9±0.3	19.5±0.4
CD+Paper3	29.6±0.6	21.4±0.1	42.1±0.9
CD+Carton	30.3±0.7	21.3±0.1	28.0±0.3
CD+Soil1	26.1±0.5	14.5±0.2	18.7±0.2
CD+Soil2	34.9±0.9	13.5±0.2	18.7±0.2
CD+Starch	16.5±0.4	23.6±0.1	24.0±0.3
Sawdust+GA	4.4±0.4	19.5±0.2	86.2±3.0
Wood Charcoal	8.9±0.3	25.3±0.2	18.2±0.3
LSD[3]	1.70	0.47	2.92

[1]CD=Charcoal dust, [2]GA=gum arabica, ± Standard error, [3]LSD is for briquettes

Sawdust+GA had ash content within the range of 0.5% to 12% of biomass fuels, while all CD briquettes had values above that range[24]. The high ash content in CD+Soil2 compared to that in CD+Soil1 is explained by the higher concentration of soil (36%) in the former than 20% in the latter. The ash content in CD briquettes were in general higher than that of wood charcoal material (Table 5.2; Table 5.3). These is caused by the generally high contents of ash forming elements[25] that could have come from contamination by soil. Briquettes made of CDOnly had clearly higher ash content compared to wood charcoal which shows the level of contamination in the former.The contamination is probably from soil introduced during the handling of raw material at the source. Charcoal dust used in briquette production is collected from heaps on the ground at charcoal retailing stalls or dumpsites. The suggestion of soil contamination was also reported in fuel from tree stumps through less careful field handling of the biomass resulting in high ash content [10].

The high ash content measured in CD briquettes led in general to lower calorific values compared to wood charcoal material. Lower calorific values were measured in the CD briquettes particularly CD+Soil2 which also had the highest ash content (Table 5.3).

The correlation between ash content and calorific value is shown in Fig. 2. Charcoal briquette showed a strong negative correlation between ash content and calorific value with R^2 values above 0.6 while Sawdust+GA had a weak correlation with R^2 value of 0.2 (Figure 5.2). Correlation between these two factors has been reported earlier[25]. Our findings are also in agreement with the results of a study carried out in Nigeria on saw dust fuel briquetes[13.]

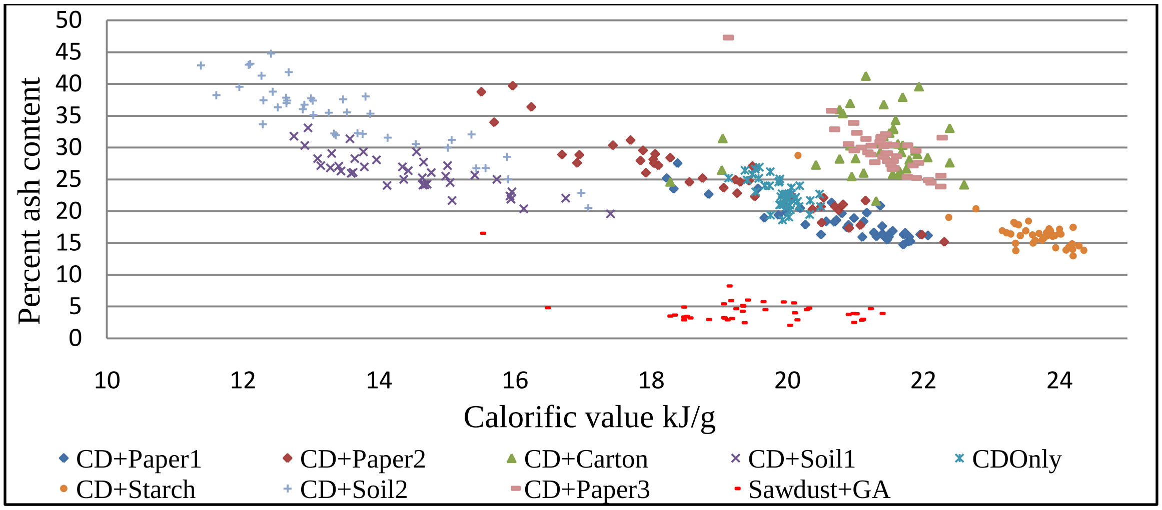

Figure 5.2. Scatter graph on ash content and calorific value in briquette

The calorific value of briquettes ranged from 13.5 kJ/g to 23.6 kJ/g which is comparable to 18 kJ/g to 22 kJ/g found in biomass fuel[24]. The highest calorific values were recorded in CD+Starch while the lowest was in CD+Soil2 (Table 5.2). The high calorific value in CD+Starch could have resulted from the high carbon content in charcoal as this briquette was 95% charcoal dust and 5% binder [24] (Figure 5.1) . Soil on the other hand caused the low calorific value and high concentration of ash in CD+Soil2 (Table 5.2). The results of this study agrees with results in previous studies that showed type of raw materials and proportions used influnce calorific value. For example, a study carried out on rice straw briquettes in China showed that calorific value increased with increase in the proportion of rice bran which was used as a binder[26].

Sawdust+GA had higher calorific value than briquettes made from charcoal dust bonded with soil(Table 2). This shows that the former has a good potential for recycling sawdust which has a calorific value of 19.8 kJ/g[24]. Briquette CD+Paper1, CD+Paper2 and

CD+Paper3 made from the same raw material and binder had calorific values that were significantly different at 95% confidence level and similar results were found in briquette CD+Soil1 and CD+Soil2.

The results show that there is potential in production of good quality cooking fuel from recycling charcoal dust and sawdust. The briquettes in this study had calorific values exceeding 14.1kJ/g which was obtained in maize cob briquettes[27]. The briquettes studied also had calorific values higher than 13.5kJ/g and 14.0kJ/g in firewood of five-year-old *Leucaenaleucocephala* and *Tectonagrandis* respectively recorded in Nigeria[28]

Volatile matter in briquette ranged from 19% to 86% and CD+Soil2 had the lowest while Sawdust+GA had the highest. The high volatile matter in sawdust+GA may have resulted from gum arabica considering that volatile matter in sawdust is 55% as indicate by Vassilev et al.,[29]. Volatile matter is highly reactive and may have caused the short burning period of one hour in sawdust+GA briquette[24]. Sawdust+GA was also the only type of briquette that burned with a flame. There was also high content of volatile matter in CD+Paper3 and CD+Carton which had high proportion of paper and carton at 36% and 46% respectively. However due to the large variations in type of paper used by different community groups when producing fuel briquettes it is difficult to make a direct correlation between various blending ratios of paper and parameters such as volatile matter and chemical elements presented in Table 3. Experiments performed under controlled conditions, dealing with the influnce of proportion of paper on ash content, volatile matter and calorific value, are ongoing.

5.3.2 Concentration of chemial elements in briquettes

The Total X-ray Florescence Spectroscopy on multiple elements, showed that sodium (Na), aluminium (Al), iron (Fe), potassium (K) and calcium (Ca) were most abundant of the elements measured while chromium (Cr), mercury (Hg) and lead (Pb) were present in smaller amounts (Table 5.3). The results of analysis of variance showed that there was a significant difference at 95% confodence level in the means of all elements between the briquettes.

The highest levels of Al were measured in CD+Soil1 and CD+Soil2 while Sawdust+GA had the lowest (Table 5.3). The presence of plant nutrients such as phosphourous (P) and potassium (K) in briquettes imply that the ash content would be an important resource for soil fertility management. However, due to presence of heavy metals, care has to be taken to avoid soil contamination. All CD briquettes contained higher concentrations of Cr, Hg and Pb than the sawdust briquettes and the wood charcoal (Table 5.3). The Hg concentrations were higher than the concentrations acceptable in soil in United Kingdom in all CD briquettes[30]. High concentrations of Cr, Hg and Pb were found in CDOnly, CD+Soil1 and CD+Starch, and in CD+Carton, CD+Paper2 and CD+Soil2 there were high concentrations of one of Cr, Hg and Pb elements. The high concentrations of heavy metals in these briquettes can be related to the source of raw materials and binders which were collected from heaps of charcoal dust in informal settlements and dumpsites (Table 1). Charcoal dust, paper or carton may have been contaminated with wastes such as scrap metal, paints and car batteries. Because in informal settlements in Nairobi, these waste types are commonly present in open spaces where charcoal dust is heaped and in dumping sites have all types of waste mixed up. Due to absence of data on heavy metal contamination in urban areas there is need for further investigations into sources of contamination in briquettes. A study in Kibera slums focused on sources of heavy metals in soil used in sack gardening and in vegetables produced from sack gardens, showed similar results (Gallaher et al., forthcoming). Soils sourced from dumpsites and vegetables grown in sack gardens with soil sourced from dumpsites had high concentrations of Cr and Pb.

Table 5.3. Concentration of chemical elements in briquettes and wood charcoal material

Type of fuel	Na	P	K	Fe	Al	Ca	Cr	Hg	Pb
	g/kg						mg/kg		
CD only	23.1	0.5±0.05	17.7±0.9	16.4±1.2	20.8±2.2	49.7±2.7	23.9±2.2	7.9±0.7	19.2±1.2
CD+Paper1	26.3±0.7	0.5±0.03	15.9±0.7	14.7±0.9	14.9±0.9	34.5±0.8	3.4±0.6	4.5±0.5	10.71±1.3
CD+Paper2	23.2±1.6	0.4±0.05	19.1±1.2	26.8±0.4	20.3±2.1	33.9±4.5	3.9±1.3	7.6±1.0	31.7±7.6
CD+Paper3	24.8±1.4	0.3±0.02	8.4±0.2	7.7±0.5	7.8±0.5	56.1±0.6	11.7±1.7	4.6±0.4	2.3±0.6
CD+Carton	24.3±1.1	0.4±0.03	17.3±1.2	9.6±0.6	15.8±1.2	43.4±1.2	85.7±14.0	3.7±0.4	9.0±1.0
CD+Soil1	19.0	0.4	13.8	33.5	31.3	33.2	23.4	10.8	15.4
CD+Soil2	17.4±1.1	0.3±0.03	16.2±0.5	27.1±0.8	31.7±1.1	27.8±2.6	4.0±0.6	7.3±1.0	24.0±1.5
CD+Starch	29.0±0.8	0.5±0.02	13.5±0.3	7.8±0.3	7.6±0.3	62.0±1.6	7.5±1.4	4.3±0.3	28.7±6.3
Sawdust+GA	25.4±2.3	0.2	3.0±0.07	0.7±0.3	0.8±0.1	6.6±0.8	2.1±0.8	0.1±0.1	0.3+0.3
Wood charcoal	33.0±0.8	0.6±0.02	21.1±0.4	1.5±0.2	4.8±0.6	34.1±0.7	0.9±0.2	0.1	Not detected
LSD[1]	5.5	0.2	3.9	9.8	6.4	12.1	21.2	3.1	21.6
Acceptable limit in soil							75-100 [31]	0.13 [30]	84[32]

[1] Least significance difference, $p<0.05$, NA, P, K, Fe and Al (g/kg), Cr,Hg and Pb (mg/kg)

Concentrations of heavy metals in biomass fuel are of considerable importance for sustainable ash utilization and disposal. If ash is disposed of in farm lands the heavy metals would enter the food chain through uptake by plants and become a concern for human toxicity potential (HTP). Contamination could also come from soil and/or water. Similar observations were reported in a study on wastewater farming in Nairobi, Kenya where continued application of contaminated irrigation water was associated with accumulation of Pb and Cr in soil[32]. It is however important to note that biomass fuel contains heavy metals such as Pb and Hg to some degree[24]. To avoid contamination of briquettes with heavy metals, charcoal dust used in briquette production should be sourced before its dumped.

5.3.3 Indoor air concentrations from burning briquettes

When the briquettes were burned in the stove, average concentration of carbon monoxide (CO), fine particulate matter ($PM_{2.5}$) and carbon dioxide (CO_2) in indoor air during the burning period were as shown in Table 5.4.

Table 5.4. Average indoor air concentrations from burning briquettes

Type of fuel	CO in ppm	$PM_{2.5}$in mg/m^3	CO_2 in ppm
CD+Paper1	24.7	0.06	90.3
CD+Carton	21.1	0.18	83.4
CD+Soil2	14.5	0.03	85.2
CD+Starch	27.7	0.04	123
Sawdust+GA	27.5	123.3	115.8
Wood charcoal	42.5	0.26	173

Values are means of 3 replicates. Values excluded background CO_2 of 349 measured at Chiromo campus, University of Nairobi.

5.3.3.1 Carbon monoxide

CD+Soil2 caused the lowest indoor air concentration of CO and had the longest burning time. Briquettes caused lower CO concentration than wood charcoal (Table 5.4). Higher concentrations of CO were recorded during the first hour of burning briquette and wood charcoal, hence the exposure to indoor air pollution declined with time (Figure 5.3). The lower indoor concentration of CO by briquettes compared to wood charcoal could be associated to higher carbon content in the latter[24]. The other reason that may have caused low CO concentrations in briquetes could be their slow burning.

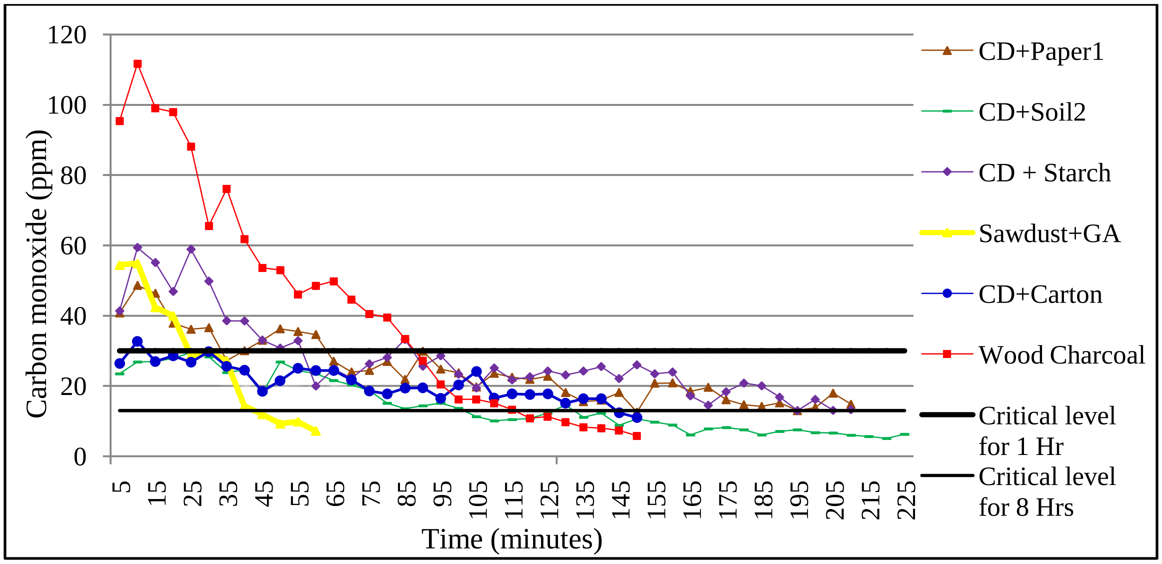

Figure 5.3.Indoor air concentrations of carbon monoxide during burning briquettes.

During their first hour of burning, all briquettes caused lower emissions of CO than wood charcoal. Two briquette types (CD+Soil2 and CD+Carton) caused CO concentrations below the critical limit of 30 ppm allowed for human exposure for one hour [33]. In the second hour of burning only CD+Soil2 achieved the 13ppm allowed for eight hours (Fig. 3). This implies that this type of briquette meets the standards set to protect people from exposure to indoor air pollution. Burning of the rest of the briquettes caused indoor air concentration with CO between 13 and 30ppm during the second hour of burning.

5.3.3.2 Fine particulate matter ($PM_{2.5}$)

The highest average indoor air concentration of fine particulate matter ($PM_{2.5}$) was obtained by burning briquettes made of Sawdust+GA and the lowest by CD+Soil2 (Table 4). The concentration of $PM_{2.5}$ from Sawdust+GA was several hundred times higher than all CD briquettes and wood charcoal (Table 5.4; Figure 5.4). As mentioned earlier, briquettes containing gum arabica (GA) had a high content of volatile matter, but there is no evidence of possible correlation between high indoor air concentration of $PM_{2.5}$ and volatile matter content. Further studies on the extremely high level of $PM_{2.5}$ in connection with Sawdust+GA briquettes combustion are required.

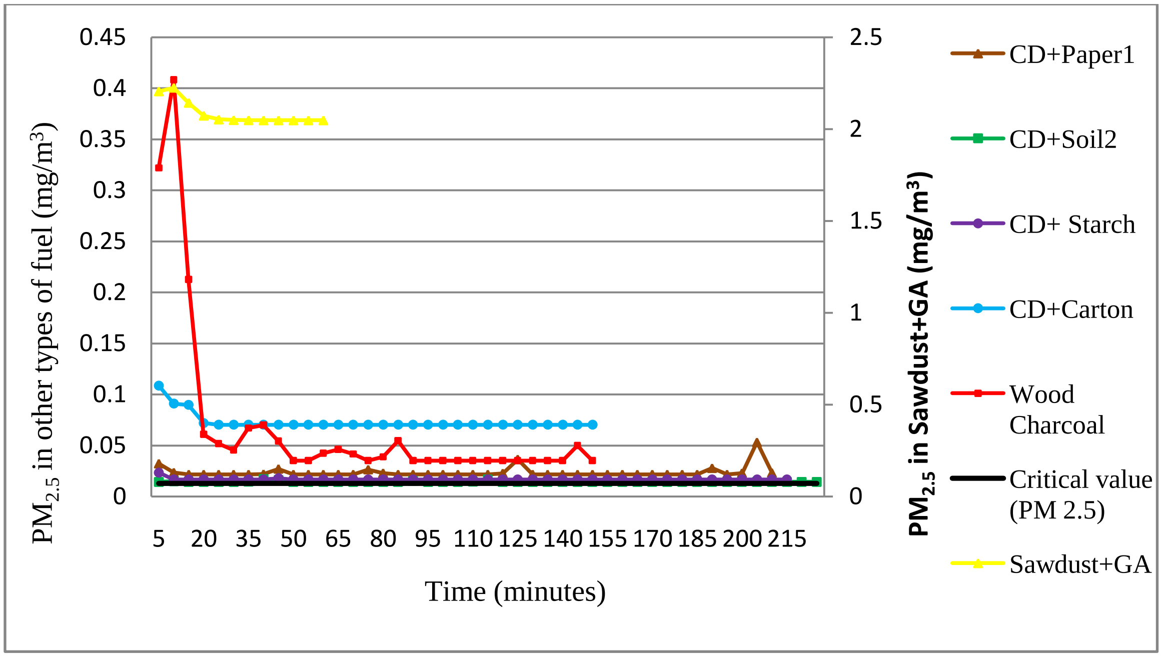

Figure 5.4. Particulate matter emitted from burning briquettes.

The combustion of wood and other biomass fuels can be an important source of particulate air pollution, with combustion particles being largely in the fine mode ($PM_{2.5}$)[20]. The average $PM_{2.5}$ from briquette CD+Soil2 was below the critical limit of $0.025 mg/m^3$ ($25 \mu g/m^3$) allowed for $PM_{2.5}$ for 24 hours during its four hour burning period[18]. This implies that this type of briquette is the safest to human health. The $PM_{2.5}$concentration from CD+Starch and CD+Paper1 were only slightly above the critical limit. Particulate matter may also play an important role in climate change. Some types of particulate matter may heat the atmosphere, while other particles may have a cooling effect. Particulate matter containing black carbon is created by incomplete combustion of fossil fuels or biomass and may have a warming effect on the atmosphere[34].

5.3.3.2 Carbon dioxide

Indoor air concentrations of carbon dioxide from wood charcoal was higher than that from briquettes (Table 4). It is commonly assumed that biomass fuel cycles based on renewable harvesting of wood or agricultural wastes are greenhouse-gas (GHG) neutral. This is because the combusted carbon in the form of CO_2 was recently and will again be taken up by regrowing vegetation. Thus, the two fifths or more of the world's households relying on such fuels are generally not thought to play a significant role in GHG emissions, except where the wood or other biomass they use is not replanted after harvest[35]. As illustrated in this study, biomass fuel converts substantial fuel carbon to products of incomplete combustion, as such their global warming potential (GWP) per meal should be of interest. Research, development and policy initiatives on briquette and wood charcoal should include cost-effective GHG reduction strategies such as more efficient cook stoves.

Results of the emissions of CO, $PM_{2.5}$ and CO_2 from briquettes as well as from wood charcaol indicate the need of households using biomass fuel for cooking to take measures to ensure sufficient ventilations in the dwelling as well as using efficient cook stoves. For intance use of imporved Kenya Ceramic Jiko (KCJ) as opposed to the traditional type for cooking reduced emission of CO by 15% [36]

5.4. CONCLUSIONS AND RECOMMENDATIONS

The quality of briquettes produced from charcoal dust and sawdust presents them as a good source of cooking fuel. The calorific value of the briquettes were acceptable in comparison to other biomass fuels. Soil contamination was found to increase ash content in charcoal dust briquettes. The soil contamination could have resulted from poor handling of charcoal dust at the selling places and its disposal in open grounds. Sourcing of raw materials and binders from dumping sites causes contamination of briquettes with heavy metals and as such there is need for further research to identify sources for each element. The studied CD briquettes performed better than wood charcoal regarding indoor air concentrations of CO, CO_2 and $PM_{2.5}$. Charcoal dust briquettes bonded with soil was the safest in terms of carbon monoxide and fine particulate matter emissions when burned. On the other hand high concentrations of fine particulate matter were released when sawdust briquettes bonded with gum arabica were burned. When briquettes intended as cooking fuel are produced, the effect of raw materials on fuel quality and on indoor air quality should be carefully considered.

5.5 ACKNOWLEDGEMENTS

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CHAPTER 6: COMBUSTION AND EMISSIONS CHARACTERISTICS OF FUEL BRIQUETTES MADE FROM CHARCOAL DUSTS AND SAWDUST OF SELECTED TREE SPECIES IN KENYA

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ABSTRACT

Charcoal is the principal fuel in Kenya providing energy for 82% of urban and 34% of rural households. Due to the high costs of cooking fuel some poor urban households are using unsafe sources such as plastic bottles, bags, shoes and basins.Faced with poverty, unemployment and challenges in accessing cooking energy, poor communities compress organic by-products into fuel briquette used as an alternative to charcoal or firewood. This paper presents results on calorific value, percent ash content and percent volatile matter and indoor air concentrations (IAC) of carbon monoxide (CO), fine particulate matter ($PM_{2.5}$) and carbon dioxide (CO_2) emitted from burning fuel briquettes. The fuel briquettes were made through experiments using charcoal dusts and sawdust from selected tree species. Biodegradable waste paper, soil, cowdung and gum arabicaresin were used in binding charcoal dusts while sawdust was bonded with gum arabicaresin. Type of binder used influenced combustion properties of fuel briquettes made from charcoal dust. Type of tree species from which charcoal dust was sourced influenced combustion properties and IAC of $PM_{2.5}$ of fuel briquettes while type of sawdust influencedIAC of PM$_{2.5}$.*Eucalyptusspp* and *Grevillia robusta* are the promising species forhigh calorific value charcoal briquettes while *Acacia xanthophloea*and*Cupressus lusitanica*had the best performance in respect to IAC of PM$_{2.5}$. Charcoal dust briquettes performed the best when both combustion and emission qualities were considered. Raw sawdust briquettes emit higher PM$_{2.5}$ than charcoal briquettes. Carbonizing raw sawdust and using it for fuel briquette production increased calorific value by 40% and reduced IAC of CO and PM$_{2.5}$ by 67% and 98% respectively. There is a need for technical and financial capacity building of community groups on techniques that will improve the quality of their fuel briquettes.

Key words: indoor air concentration (IAC), fuel briquettes, cooking fuel, tree species

6.1 INTRODUCTION

About 2.4 billion people use solid biomass fuels as a source of energy for cooking and heating (Kaygusuz, 2011). In Sub Saharan Africa (SSA) 72% of urban and 98% of rural households use woodfuel for energy (Bailis et al., 2005). In Kenya charcoal is the principal fuel witha per capita use estimated at 150kg and an annual national consumption of 1.6 to 2.4 million tons where 82% of urban and 34% of rural households depend on it (Karekezi, 2002; MoE, 2002; Mutimba and Barasa, 2005). Dependence on charcoal for cooking is similar in Tanzania, Zambia, and Ethiopia, where 80%, 85%, and 70% of urban households respectively rely upon it (Ngeregeza, 2003; Chidumayo et al., 2002; Yigard 2002). The poor populations, who are the main users of charcoal, cannot afford to use electricity and/or liquid petroleum gas (LPG) for cooking because of the high costs of fuel and related cooking appliances (Mugo et al,. 2007). As populations rise, cooking fuel is becoming increasingly expensive and poor households are opting to use unhealthy sources of fuel such as rubber from tyres, old shoes and plastics especially those in urban and peri-urban areas (Wagathui and Ngugi, 2010). Due to the high cost of cooking fuel, many families are shifting away from traditional meals that require long cooking times and are compromising dietary diversity and nutrition as a result (Njenga et al., 2013).

Most of the charcoal used in Kenya is obtained from trees on farms and private land (Mutimba and Barasa, 2005). Nearly all charcoal consumed in Kenya and elsewhere in sub-Saharan Africa (SSA) is made from local tree species and over 100 tree species are used in charcoal production in Kenya. Some of the preferred trees include Acacia, Croton, Olea, Manilkara, Mangifera, Eucalyptus and Euclea species (Mutimba and Barasa, 2005). Charcoal from hardwood is preferred because of its high density and calorific value (Mugo et al., 2007). There is about10-15% loss of charcoal in form of dust or fines due to breakages during transportation and storage associated with poor packaging and handling. This waste accumulates at the retailing points where it is left as waste heaps or burned. About 230 000 tons of sawdust are generated annually from sawmills most of which poses disposal challenges and the majority is burnt on site. The most common tree species sawn for timber production include *Cupressus lusitanic, Pinus patula* and *Grevillia rubusta* (Maundu and Tengnas, 2005).

Household biomass energy use is a major component of GHG emissions in many developing countries but little attention has been given to the associated human health and climate related risks (Bailis, 2003). Exposure to indoor air pollution, especially particulate matter, from the combustion of biofuels (wood, charcoal, agricultural residues, and dung) has been found to cause respiratory diseases in developing countries that results in over 1.6 million deaths globally and 400,000 in sub-Sahara Africa (Ezzati et al., 2002).If nothing is done to curb this problem, it is projected that 9.8 million premature deaths will occur by the year 2030 (Bailis, et al., 2005). Poverty is linked to household air pollution from use of unprocessed biomass fuels (wood, animal dung, and crop wastes) in simple stoves (The Lancet, 2008).

Particulate matter containing black carbon is created by incomplete combustion of fossil fuels or biomass and may have a warming effect on the atmosphere (Ramanathan and Carmichael, 2008). As an important component of particulate matter black carbon is the third largest warming agent, following CO_2 and methane (Sato et al., 2003). Carbon monoxide is an important gas to measure from burning biomass fuel as it indirectly affects global warming (Pennise et al., 2001). In addition CO is absorbed by the lungs where it reacts with hemoglobin to form carboxyhemoglobin (COHb) which reduces the oxygen carrying capacity of the blood (Kirk-Othmer, (1985). Measuring CO_2 from burning biomass is necessary as it is an important greenhouse gas (GHG) that directly absorbs some of the Earth’s outgoing radiation in the atmosphere (Pennise et al., 2001). Even though as long as the trees are sustainably harvested and no deforestation occurs climate impact from cooking a meal with biomass energy is low (Njenga et al., unpublished). Mitigation of climate change has become a major driver of energy policies and programs at the national and global levels and an important factor in designing efforts to improve provision of household cooking services to the world's poor (Foell et al., 2011).

Faced with poverty, unemployment and challenges in accessing affordable cooking fuel, communities are turning to fuel briquette which is made by compressing biomass material into a uniform solid unit (Sotannde et al., 2010). Briquetting of biomass is done using various techniques, either with or without binder addition. For biomass materials that lack plasticity, addition of a binding or agglomerating material, preferably combustible is required to enable the formation of solid fuel briquettes (Rousseta et al., 2011). Common binders are starch, soil, animal dung or waste paper. Charcoal dust and saw dust present huge potential for fuel briquette making. Biomass residues generated by the wood-based industry in most developing countries have potential for fuel briquette production as demonstrated in Cuba, Nigeria, Brazil, China, and Kenya (Suarez et al., 2000; Sotannde et al., 2010; Rousseta et al., 2011; Gominho et al., 2012; Wamukoya and Jenkins, 1995).Agricultural by-products are used in fuel briquette production such as rice straw and rice bran in China (Chou et al., 2009), maize cobs in Thailand (Wilaipon, 2007) and coffee husks in Brazil (Felfli et al. 2010). Adoption of fuel briquette is spreading in Kenya's urban and rural areas and the type of fuel briquettes produced depends on the locally available material. A study by Terra Nuova and AMREF Kenya showed that sugar bagasse was used in Mumias, charcoal dust was used in Nairobi, coffee husks were used in Kiambu/Muranga, gum arabica was used in Isiolo, tree leaves were used in Machakos/Makueni, water hyacinth was used in Kisumu and rice husks were used in Mwea (Terra Nuova and Amref-Kenya, 2007).

This study was carried with the aim of establishing combustion properties and indoor air concentrations (IAC) of CO, $PM_{2.5}$ and CO_2 from fuel briquettes produced from charcoal dusts of *Acacia mearnsii*,*Eucalyptus spp* and *Acacia xanthophloea* and sawdust of *Grevillia robusta, Pinus patula*and*Cupressus lusitanica*selected tree species. The additional aim is to improve the quality of fuel briquettes produced in Kenya and in the region and offer advice on selection of agroforestry tree species for biomass energy.

6.2. MATERIALS AND METHODS

6.2.1 Sources and types of organic materials/residues and binders

The fuel briquette production experiments were carried out at the Department of Land Resource Management and Agricultural Technology, University of Nairobi. This study tested (i) four binders namely paper, soil, cowdung and gum Arabica in binding *Acacia mearnsii* charcoal dust fuel briquettes, (ii) two types of machines which included metal and wooden press in production of *Acacia mearnsii* charcoal dust fuel briquettes bonded with either paper, soil, cowdung or gum Arabica (iii) charcoal dusts from three tree species which included *Acacia mearnsii*, *Eucalyptus spp and Acacia xanthophloea* bonded with paper, (iv) raw sawdusts from three tree species namely *Grevillia robusta, Pinus patula*and*Cupressus lusitanica* bonded with gum arabica and (v) carbonized sawdusts from the three tree species in (iv) bound with gum arabica. Charcoals from *Acacia mearnsii*,*Eucalyptus spp* and *Acacia xanthophloea* were considered as the control.

Charcoal was sourced from three tree species commonly used for charcoal in the country namely *Acacia mearnsii*,*Eucalyptus spp* and *Acacia xanthophloea*. Sawdusts were sourced from three tree species commonly used for timber production namely *Grevillia robusta*,*Pinus patula*and *Cupressus lusitanica*. Geographical distribution of the tree species in the country was another criteria used in selecting the tree species (Table 6.1).

Table 6.1 Characteristics of tree species from which charcoal dusts and sawdusts were sourced

Tree species	Source of charcoal and sawdusts	Age of tree (years)	Wood density g/m^3	Calorific value of wood (kJ/g)	Agro-climatic zone
Acacia mearnsii	Small-scale farm at Lari, Kiambu	8-10	0.66	14.6-19-2(a)	I-III
*Eucalyptus spp**	Kakuzi Ltd, Thika: a commercial charcoal producer from plantations	8-10	0.54-0.78	19.7-20.0(b)	
Acacia xanthophloea	Rarieda, Siaya: Small-scale farm at of a contact farmer for research on charcoal production by KEFRI	8-10	0.90	21.5(c)	III-V
Grevillia robusta	Sawmill at Meru and logs were from small-scale farmers	15-20	0.65	20.1(d)	II-V
Pinus patula	Sawmill at Lari, Kiambu and logs were from government forest plantation	25-30	0.45	12.6(e)	I-III
Cupressus lusitanica	Sawmill at Lari, Kiambu and logs were from government forest plantation	25-30	0.65	18.4(f)	II-III

*Charcoal dust was of a mixture of *Eucalyptu grandii* and *E. camaldulensis* with the former being over 80%, National Academy of Sciences, (1980)(a), Bolza & Keating, (1972)(b), Little, 1981(c), ICRAF, (1992)(d), Lyons et al. (1985)(e), EC-FAO, (2001)(f)

A tradition kiln with a yield efficiency of 10-18.2% by weight was used to produce *Acacia mearnsii* charcoal (Okello et al., 2001), an improved kiln called Masonry with efficiency of 33% was used to produce *Eucalyptus spp* charcoal (Kakuzi, 2003) and *Acacia xanthophloea* charcoal was produced using an improved kiln, Casamance with efficiency of 26-30% (Oduor et al., 2006). The age of the trees in table 1 was provided by the supplier – namely, small-scale farmers, Kakuzi Ltd and the government Forest department. The research team ensured that sawdusts were only from the specified tree species by checking during milling at the sawmills.

The binders used in the experiments were biodegradable waste paper, soil, cowdung and gum arabica resin. The soil was sourced from an open pit at the livestock fields at the College of Agriculture and Veterinary Sciences (CAVS), University of Nairobi, Kabete campus which was close to the plant where the briquettes were being produced. The soil type is humic Nitisol with 70 % clay and was dug at a depth of 60 centimetres (FAO-UNESCO System, 1990; Gachene 1997). Cowdung was collected from a cattle shed at the same site where soil was sourced. Shredded paper was sourced from African Population and Health Research Centre (APHRC). Gum Aarabica resin was sourced from Isiolo and it was the left over after the good grade is sold for cosmetics.

6.2.2 Briquette production procedures

Charcoal was fine ground and sieved through 5 mm holes using a nylon net (recycled). Sawdusts were dried in the sun to between 12-17% moisture content, passed through the same sieve and then carbonized using a drum kiln which was designed by Kenya Forestry Research Institute (KEFRI), for details see Oduor et al. (2006). Further the paper was schredded into small pieces and then soaked in water for 2 to 3 hours while gum arabica was soaked in water overnight. Cowdung was dried in the sun to 19% moisture content after which it was passed through the above mentioned sieve. Dry weights of raw materials and binders were taken. The processed raw materials and binders were mixed in water in the proportions given in Table 6.2. To test if the mixed slurry bonded well, the slurry was squeezed in one hand and then held between two fingers and if it fell apart, more binder was added until it held together. This way optimal mixing ratio between the raw material and the binder were calculated as their dry weights were taken before mixing. The mixed slurry was compacted using both manual wooden and metal presses into circular solid blocks with a small hole in the middle.

Table 6.2 List of organic residues and binders used to produce different types of fuel briquette .

Organic material	Type and proportion of binder in parenthesis	Type of Briquette
Charcoal dust from *Acacia mearnsii*	Paper (13%)	CD+Paper1A
Charcoal dust from *Acacia mearnsii*	Paper (13%)	CD+Paper1B*
Charcoal dust from *Eucalyptus spp*	Paper (13%)	CD+Paper2
Charcoal dust from *Acacia xanthophloea*	Paper (13%)	CD+Paper3
Charcoal dust from *Acacia mearnsii*	Soil (20%)	CD+SoilA
Charcoal dust from *Acacia mearnsii*	Soil (20%)	CD+SoilB*
Charcoal dust from *Acacia mearnsii*	Cowdung (32%)	CD+CowdungA
Charcoal dust from *Acacia mearnsii*	Cowdung (32%)	CD+CowdungB*
Charcoal dust from *Acacia mearnsii*	Gum arabica (5%)	CD+GAA
Charcoal dust from *Acacia mearnsii*	Gum arabica (5%)	CD+GAB*
Sawdust from *Grevillia robusta*	Gum arabica (9%)	Sawdust+GA1
Sawdust from *Pinus patula*	Gum arabica (11%)	Sawdust+GA2
Sawdust from *Cupressus lusitanica*	Gum arabica (11%)	Sawdust+GA3
Carbonized sawdust from *Grevillia robusta*	Gum arabica (8%)	Csawdust+GA1
Carbonized sawdust from *Pinus patula*	Gum arabica (10%)	Csawdust+GA2
Carbonised sawdust from *Cupressus lusitanica*	Gum arabica (10%)	Csawdust+GA3

CD=Charcoal dust, GA=Gum Arabica and Csawdust=carbonized sawdust, *Pressed using metal machine

6.2.3 Determination of calorific value of fuel briquettes

Infrared (IR) Spectroscopy following procedures described by Shepherd and Walsh (2007) using the MPA Multi Purpose FT-NIR Analyzer was applied to establish a spectral library of the total 760 samples from 16 treatments each with sample size of 40 (n). Based on the chemical and physical spectral diversity in the library, a representative subset of 64 samples was selected to represent the 16 treatments (table 2) and the sample size (n) ranged between 2-11. The subset samples were analysed for calorific value, ash content and volatile matter following procedures described by Findlay(1963). Calorific value as a measure of heating value was analysed using bomb calorimeter; volatile matter was measured using 0.5g of the sample which was heated in a furnace at 800^{o}C for five minutes. Volatile matter was then expressed as the percentage of loss of weight of the original sample. The ash content was determined using similar procedure to that ofvolatile matter but the sample was heated for 1.5 to 2 hours. Calibration based on the 64 samples was used to predict calorific value for the entire 760 sample spectral library as described by Shepherd and Walsh (2007).

6.2.4. Determination of IAC of CO, $PM_{2.5}$ and CO_2 from burning fuel briquettes

Indoor air concentration of CO, PM $_{2.5}$ and CO_2 were measured by burning an amount of fuel that filled the small-sized energy saving cook stove called Kenya Ceramic Jiko (KCJ) and an aluminium cooking pot containing water with dimension that fitted the cook stove was placed on top, as practiced by households. Kenya Ceramic Jiko (KCJ) was chosen as it is used by 85% of households in urban areas with an energy conversion efficiency of about 33-35% compared to 10-15% obtained in traditional stoves (Mugo et al., 2007). Measurements were carried out in triplicates in a kitchen measuring 3.4 by 3 metres with a door measuring 2 by 0.9 metres and two windows each measuring 0.8 by 0.6 metres. One of the windows was kept open while the other was closed simulating household cooking conditions. Measurements were taken throughout the burning period of each type of fuel. 420 grams of each fuel type was burned.

All measuring equipments were suspended with a rope one metre above and one metre away from the cooking stove, simulating the height of a person cooking. CO was measured at 10 seconds intervals using EL-USB-CO carbon monoxide data logger DATAQ Instruments (603-746-5524). $PM_{2.5}$ measurements were taken per minute using a particulate matter meter, UCB, Berkeley Air Monitoring Group (SN 1311). CO_2 was measured at intervals of five minutes using Taile 7001 Carbon Dioxide and Temperature metre, LASCAR (603-746-5524).

6.2.5 Data management and analysis

Data was managed using Microsoft Excel software and analysed for descriptive statistics such as mean and standard error using the same sofware. Genstat Edition 13 was used for One Way Analysis of Variance (ANOVA) (VSN International 2012). Significance of difference between any two means was tested using the least significant difference of means (LSD).Actual probability values have been presented as ‘p’ to show significance at confidence level of 95%.

6.3. RESULTS AND DISCUSSIONS

5.3.1 Combustion properties of fuel briquettes and charcoal

The type of binders used in *A. mearnsii* charcoal dust fuel briquette production had a significant difference ($P<0.05$) in calorific value (Table 6.3). The best binder for *A. mearnsii* charcoal dust with respect to calorific value was gum arabica (CD+GAA)while cowdung was the lowest (CD+CowdungA) and the difference between their means was higher than the LSD value indicating a significance difference ($p<0.05$).There was also significant difference ($p<0.05$) in calorific value between fuel briquettes and charcoals.

Table 6.3. Mean ash content (%), calorific value (kJ/g) and volatile matter (%) of fuel briquettes and charcoals.

Fuel type	Ash	Calorific value (kJ/g)	Volatile matter
CD+Paper1A	3.5±0.2	25.3±0.5	27.0±0.5
CD+SoilA	6.3±0.3	24.5±0.4	22.5±0.4
CD+CowdungA	7.4±0.3	23.3±0.5	25.9±0.5
CD+GAA	2.8±0.2	28.2±0.7	26.0±0.6
Acacia mearnsii charcoal	2.6±0.1	29.0±0.6	23.2±0.4
Eucalyptus spp charcoal	2.9±0.1	27.0±0.4	27.6±0.5
Acacia xanthophloea charcoal	2.4±0.1	28.6±0.5	24.6±0.5
LSD ($p<0.05$)	0.55	3.4	1.37
$P<0.05$	0.001	0.001	0.001

CD=charcoal dust, GA=gum arabica. Values for ash contentand volatile matter are expressed as % of dry weigh.

The other type of fuel briquette with good cooking qualities was CD+SoilA as it burned for four hours (Table 6.6) making this type of fuel briquette suitable for preparing foods that require long time to cook such as dry grains – foods which many households are currently abandoning due to the high costs of fuels(Njenga et al., 2013). Pressing method, either wooden or metal led to no significant difference ($p>0.05$) in calorific value of charcoal fuel briquettes. Fuel briquete CD+GAA had calorific value higher than that of *Eucalyptus spp* charcoal (Table 6.3). Except for CD+CowdungA and CD+SoilA all the other charcoal dust fuel briquettes studied had a calorific value higher than that of charcoal (25.3 kJ/g) which was purchased from a retailer in Nairobi (Njenga et al., 2013). The heating value of the fuel briquettes has endeared them to the communities that prefer them instead of charcoal (Njenga et al., 2013).

Calorific value measured in this study for *Acacia xanthophloea* charcoal was within the range of 28.03-33.13 kJ/g reported by Oduor et al., (2008). Their study on charcoal from the above species was carried out in the same region where charcoal for this study was sourced. The calorific value for *Acacia Mearnsii* and *Eucalyptus spp* charcoals measured in this study were lower than the 31.11kJ/g and 30.02kJ/g respectively reported in Kenya by Pennise et al., (2001). This difference could be associated to differences in age of tree, species of Eucalyptus and or the environmental conditions under which the trees grew. However, the results of both studies show that *Acacia Mearnsii* has charcoal of higher calorific value than that of *Eucalyptus spp.* The volatile matter in charcoal was within the recommended range between 40-5%. Volatile matter content in charcoal is influenced by carbonization temperature and time the biomass is in the kiln (FAO, 1985).

Fuel briqiettes made from charcoal dusts from different tree species had calorific values that were significantly different ($p<0.05$). *Eucalyptus spp* charcoal was higher thanthat of *Acacia xanthophloea* and *Acacia mearnsii* (Table 6.4.).A significant difference ($p<0.05$) in gross heat of combustion was reported by El-Juhany and Aref (2003) in their study oncharcoal produced from some endemic and exotic acacia species grown in Saudi Arabia which they associated to carbon content. They further stated that other factors such as age, environmental conditions and differences in maximum final temperatures in carbonization process could have caused the differences. Further variations in combustion properties of charcoal from different tree species could be attributed to the fact that all woody matter contains cellulose, proteins, lignin, and certain secondary metabolites of variable molecular mass and composition (Robinson, 1967). These chemical compounds decompose, releasing intrinsic heat energy at certain temperatures.

Table 6.4. Mean ash content (%), calorific value (kJ/g) and volatile matter (%) of charcoal dust fuel briquettes from three tree species.

Fuel type	Ash	Calorific value (kJ/g)	Volatile matter
^{1}CD+Paper1A	3.5±0.2	25.3±0.5	27.0±0.5
^{2}CD+Paper2	2.7±0.1	27.4±0.4	31.8±0.4
^{3}CD+Paper3	4.3±0.2	26.3±0.7	24.2±0.5
LSD ($p<0.05$)	0.48	1.49	1.3
$P<0.05$	0.001	0.028	0.001

Charcoal dusts are from ^{1}*Acacia mearnsii* charcoal dust, ^{2}*Eucalyptus spp* charcoal dustand ^{3}*Acacia xanthophloea*.± is standard error. Values for ash contentand volatile matter are expressed as % of dry weigh.

Tree species from which sawdust was sourced had a significance difference ($p<0.05$) on calorific value of raw sawdust briquettes Sawdust+GA1, Sawdust+GA2 and

Sawdust+GA3(Table 6.5). Carbonizing sawdust resulted into sawdust fuel briquettes CSawdust+GA1, CSawdust+GA2 and CSawdust+GA3with no significance difference ($p<0.05$).

Table 6.5. Mean ash content (%), calorific value (kJ/g) and volatile matter (%) of raw and carbonized sawdusts fuel briquettes from three tree species

Fuel type	Ash	Calorific value (kJ/g)	Volatile matter
[1]Sawdust+GA1	3.9±0.5	19.7±1.8	89.3±0.4
[2]Sawdust+GA2	2.07±0.7	13.7±2.6	90.4±1.0
[3]Sawdust+GA3	1.4±0.0	17.8±1.1	91.6±2.1
[1]Csawdust+GA1	4.2±0.2	28.1±0.6	36.7±0.5
[2]Csawdust+GA2	3.3±0.2	26.2±0.6	41.0±0.8
[2]Csawdust+GA2	2.5±0.1	29.4±0.7	33.6±0.5
LSD ($p<0.05$)	1.43	5.36	5.8
$P<0.05$	0.001	0.001	0.001

Sawdusts are from [1]*Grevillie robusta,*[2]*Pinus patula* and [3]*Cupressus lusitanica*. Sawdust=raw sawdust, Csawdust=carbonized sawdust and GA=gum arabica. ± is standard error. Values for ash contentand volatile matter are expressed as % of dry weight.

Carbonizing sawdust before producing fuel briquettes improved calorific value by 30% in *Grevillie robusta,* 48% in *Pinus patula* and 39% in *Cupressus lusitanica,* an average increase of 40% compared to using raw sawdust. This could be due to the fact that carbonization reduced volatile matter between raw sawdust and carbonized sawdust fuel briquetes by an average of 145%. Carbonizing sawdust also increased burning period of sawdust fuel briquettes by an average of 230% (Table 6.) Volatile matter consists of low molecular-weight hydrocarbons with low combustion temperatures that decompose at low temperatures, losing energy during the initial phase of burning. Volatile matter is vaporized before homogenous gas phase combustion reactions take place (van Loo and Koppenjan, 2008).

Some fuel briquette types met the ash content below 3% recommended by FAO (FAO, 1985). These fuel briquettes include:*Acacia mearnsii* charcaol dust bonded with gum arabica (CD+GAA); *Eucalyptus* spp charcoal dust bonded with paper (CD+Paper2); *Pinus patula*raw sawdust bonded with gum arabica (Sawdust+GA2); *Cupressus lusitanica* rawsawdust bonded with gum arabica(Sawdust+GA3) andcarbonized *Pinus patula*sawdust bonded with gum arabica (Csawdust+GA2). Ash content is an important property to consider when assessing the quality of biomass fuel since the decomposition temperatures of the oxides in ash are high above the cooking temperatures (Ogur and Ayaya, 1999). The high volatile matter in fuel briquette types CD+GAA and CD+Paper1A could be associated with the gum arabica and paper which contained 85% and 77% volatile matter content respectively. This may have lowered the burning period to 150 minutes in these types of fuel briquettes as compared to charcaol dust bonded with soil (CD+SoilA) which burned for 240 minutes (Table 6). Soil had low volatile matter of 18% and it is also non-combustible, hence the long burning period (van Loo and

Koppenjan, 2008). Further, volatile matter for the charcoal and charcoal fuel briquettes in this study was within the range of 5-40% recommended by FAO (FAO, 1985).

Fuel briquettes produced in these experiments using charcoal dust bonded with either paper or soil had calorific value higher than those produced from similar feedstock by local communities in Nairobi. For instance, fuel briquette produced in Nairobi using charcoal dust bonded with paper and charcoal dust bonded with soil had 20.3kJ/g and 14kJ/g respectively Njenga et al., (2013). The increase in calorific value was 25% and 75% measured in *Acacia mearnsii*charcoal dust bonded with paper (CD+Paper1A) and *Acacia mearnsii*charcoal dust bonded with soil (CD+SoilA) respectively. This improvement could be attributed to the preparation process where homogenous fine charcoal dust particles below 5mm were used in the experiments which could have resulted into more carbon being packed in each fuel briquette as opposed to use of large inhomogeneous pieces of charcoal dust as practiced by community groups. This is supported by van Loo and Koppenjan, (2008) who argue that the higher concentration of carbon in wood fuels increases their calorific value compared to herbaceous biomass fuel. The charcaol dust used in the experiments was from a single tree species and was also free of impurities such as soil, which was only introduced as a binder. On the other hand, fuel briquette type Sawdust+GA1 with a 9% proprtion of gum arabica as a binder had calorific value similar to 19.5 kJ/g measurd in *Grevillie robusta* raw sawdust fuel briquette produced by community groups in Nairobi and surroundings using 26% proprtion of gum arabica (Njenga et al., 2013). This implies that reducing gum arabica from 26% to 9% had no effect on calorific value. This will contribute to saving money spent on purchasing gum arabica. The fuel briquettes in this study had calorific values exceeding 14.1kJ/g which was obtained in maize cob fuel briquettes (Wilaipon, 2007). The fuel briquettes studied also had calorific values higher than 13.5kJ/g and 14.0kJ/g in firewood of five-year-old *Leucaena leucocephala* and *Tectona grandis* respectively recorded in Nigeria (Fuwape, 1993).

Converting charcoal dust into fuel briquettes seems to be an obvious answer in developing viable alternative biomass cooking energy in developing countries. Charcoal dust cannot be used directly for cooking by the usual simple charcoal burning methods and hence it is more or less unusable. However, if charcoal dust could be briquetted this would result in an additional 10 to 20% fuel (FAO, 1985). Unfortunately, experience has showed that although it is technically possible to briquette charcoal fines, the economics are not usually favourable, except where the price of lump charcoal is very high and the fines are available at a very low or zero cost (FAO, 2008). This paper shows that charcoal dust fuel briquette quality is comparable to that of charcoal. In addition, local communities are supporting their livelihoods in Nairobi and surroundings through briquetting charcoal dust which is acquired at very low costs of Ksh2(US$0.02) per kg (Njenga et al., 2013). Cooking a traditional meal-mixture of green maize (*Zea mays*) and dry common bean (*Phaseolus vulgaris L.*) commonly known as G*itheri* with fuel briquettes is much cheaper at 3 ksh (US$0.04 – 850 grams) than cooking with more expensive charcoal 26 ksh (US$0.35 - 890grams of charcoal) or with kerosene, 45 ksh (US$0.6 - 0.36 litres of kerosene) (Njenga et al., 2013).

6.3.2 Concentration of indoor air polluting gases and $PM_{2.5}$ emmited from burning fuel briquettes and charcoal

The burning period of the different fuel briquettes and charcoal ranged between 30 minutes and 240 minutes (table 6.6)

Table 6.6. Type fuel briquette and length of time (minutes) taken for complete burning

Fuel type	Time take to burn completely (minutes)
CD+Paper1A	150
CD+Paper2	150
CD+Paper3	150
CD+SoilA	240
CD+CowdungA	150
CD+GAA	150
Sawdust+GA1	75
Sawdust+GA2	60
Sawdust+GA3	30
Csawdust+GA1	180
Csawdust+GA2	150
Csawdust+GA3	150
Charcoal from *A. mearnsii*	120
Charcoal from *Eucalyptus spp*	120

6.3.2.1 Carbon monoxide (CO)

Fuel briquettes made from charcoal dust bonded with soil (CD+SoilA), raw sawdust bonded with gum arabica (Sawdust+GA1, Sawdust+GA2, Sawdust+GA3) and carbonized sawdust bonded with gum arabica (Csawdust+GA1, Csawdust+GA2, Csawdust+GA3) produced CO concentrations that were below the critical limit of 30 ppm allowed for human exposure for one hour (US EPA, 2002) as shown in Figures 6.2a-2c. This could be attributed to soil being non-combustible, the low amount of gum arabica used as a binder and the carbonized sawdust.

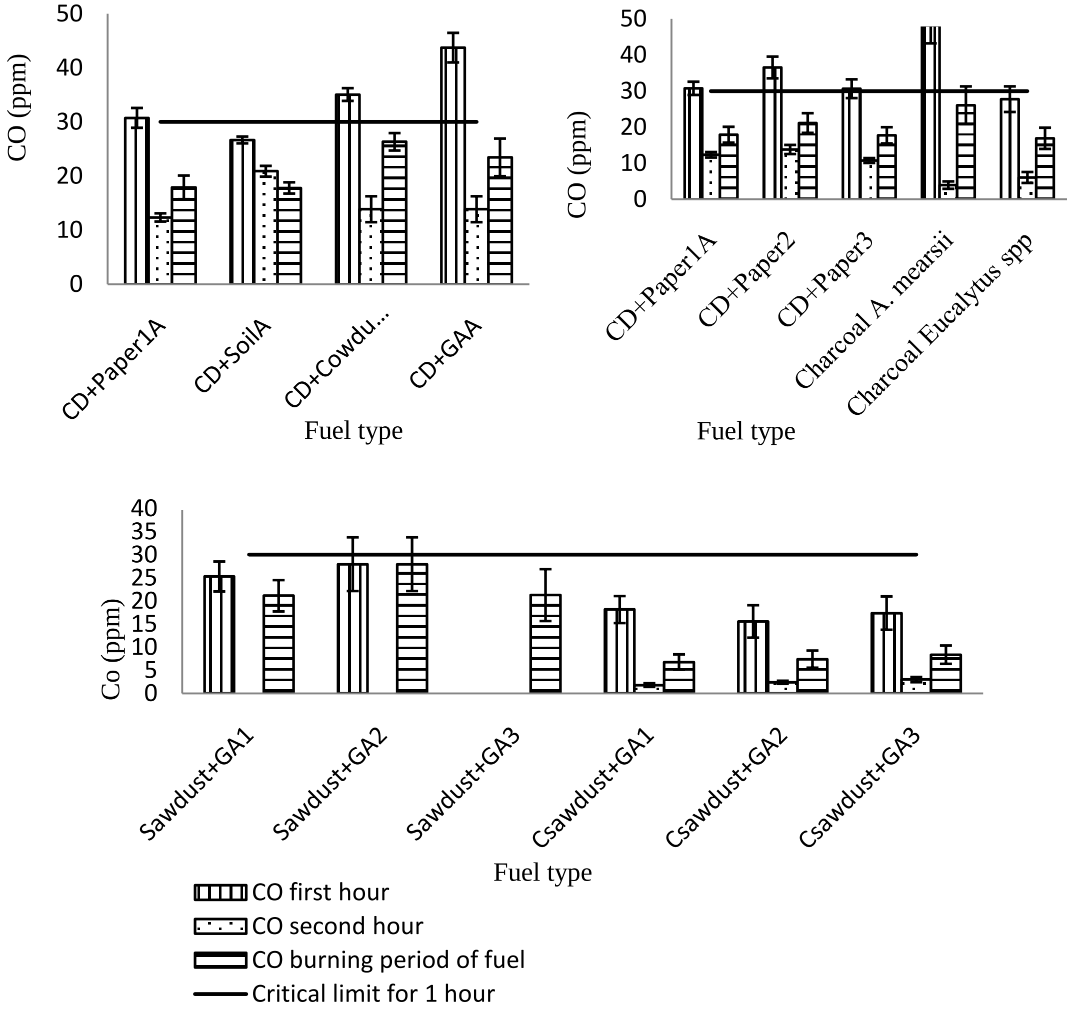

Figure 6.2a-c. Indoor air concentration of carbon monoxide (CO) (ppm) from burning fuel briquette and charcoal.Values are means of 3 replicates. CD=charcoal dust, Csawdust=carbonized sawdust

Similar results were obtained from burning coal fuel briquettes in China (Yamada et al., 2008). There was a general increase in CO emmitted during the first hour of burning both fuel briquette and charcoal, which then declined with time (Figure 6.2a-c).

Use of different binders in production of charcoal dust fuel briquettes had an influnce on the IAC of CO (Figure 2a). There was a significant difference ($p<0.05$) in means of IAC of CO among the four binders. While cowdung and gum arabica elevated CO concentration, using soil and paper reduced the amounts released into the air. This could be associated to the non-combustible characteristics of soil (van Loo and Koppenjan, 2008) and the amount of paper used for binding was also relatively small, contributing only 13% of the mixture. There was a significant difference ($p<0.05$) in CO from charcoal made from *Acacia mearnsii* (26.1 ppm)and that made from *Eucalyptus spp* (16.9 ppm) with the latter having lower amounts (Figure 6.2b). This could be attributed to the compostion of the wood matter as discussed earlier.

A study by Njenga et al. (2013)on IAC of CO from *Grevillia robusta*raw sawdust dust fuel briquette with 26% (wt) gum arabica made by a community group, reported 27.5 ppm during its burning period of one hour. The experimental *Grevillia robusta* raw sawdust fuel briquette (Sawdust+GA1) had IAC of CO lower than that measured from the community *Grevillia robusta* fresh sawdust fuel briquette by 32%. Raw materials in these two types of raw sawdust fuel briquettes were sourced from the same localities though at different times. This difference indicates potential in reducing IAC of CO from raw sawdust fuel briquettes through reducing the amount of gum arabica used as a binder. The raw sawdust fuel briquettes produced by the community group had a proportion of 26% gum arabica while in the experiments the amount was reduced to 9%.

Carbonized sawdust fuel briquettes reduced IAC of CO by 68%, 74% and 61% in *Grevilea robusta*, *Pinus patula* and *Cupressus lusitanica* respectively (Figure 2c). This reduction in CO has health benefits. There was a significant difference ($p<0.05$) between raw sawdust fuel briquettes and carbonized fuel briquettes in IAC of CO. This could be attributed to the decline in volatile matter by an average of 59% (Table 6) as carbonization caused vaporized prior to combustion (van Loo and Koppenjan, 2008).

6.3.2.2 Fine particulate matter ($Pm_{2.5}$)

The concentration of $PM_{2.5}$ was high during the early stages of burning of the fuel briquettes and charcoal (Table 6.7). These findings are in line with Wang et al., (2010) who studied the concentration of air pollutants in rural homes of China where wood was used as source of cooking energy and found that a single peak appeared only in the initial stage of combustion. A similar trend in emissions was reported in a study on particulate matter from crop residues burned in typical household stoves in China, where there was a significant difference in particulate matter between the flaming and smoldering phases (Shen et al., 2010). A possible explanation is that when wood is fed into the stove, volatile components of wood are released before they are completely combusted thereby emitting large amounts of particulate matter in the early phase of combustion (Lucio and Sampaio, 2004).

Indoor air concentration (IAC) of $PM_{2.5}$ from *Acacia mearnsii* charcoal dust fuel briquette bonded with paper (CD+Paper1A), soil (CD+SoilA), cowdung (CD+CowdungA) and gum arabica (CD+GAA) had a significant difference ($p<0.05$) and CD+SoilA and

CD+GAAperformed the best (Table 6.7). Although gum arabica has high volatile matter, a low amount is used in production of CD+GAA which could have been the cause for the the low PM$_{2.5}$.

Table 6.7. Indoor air concentration of fine particulate matter (PM$_{2.5}$) in µg/m^3 from burning charcoal dust fuel briquette made using different binders compared to charcoal

Type of fuel briquette	PM$_{2.5}$ first Hr	PM$_{2.5}$ second Hr	PM$_{2.5}$ burning period of fuel
CD+Paper1A	268.9±5.7	259.8±3.3	262.5±2.7
CD+SoilA	185.0±0.6	183.9±0.1	184.3±0.2
CD+CowdungA	380±50	198.2±0.33	271.3±3
CD+GAA	94.7±11.8	70.5	80.2±5.07
Acacia mearnsii charcoal	75.2±37.3	29.1	52.2±18.9
Eucalyptus spp charcoal	50.5±6.2	29.1	39.8±3.8
LSD (p<0.05)			34.65
p<0.05			0.001

CD=charcoal dust, GA=gum Arabica, Csawdust=carbonized sawdust, ± is standard error.

IAC of PM$_{2.5}$ was influenced by the type of tree species from which charcoal dust was sourced (Table 6.8). There was a significant difference ($p<0.05$) in IAC of PM$_{2.5}$ from fuel briquettes made from *Acacia mearnsi*, *Eucalyptus* spp and *Acacia xanthophloea*charcoal dusts. IAC of PM$_{2.5}$ from fuel briquettes made from charcoal dusts was in the order *Acacia xanthophloea* (CD+Paper3) >*Eucalyptus* spp (CD+Paper2)

>*Acacia mearnsii* (CD+Paper1A). This variation can be attributed to the chemical differences in wood matter of the tree species studied, as explained earlier.

Table 6.8. Indoor air concentration of fine particulate matter ($PM_{2.5}$) in µg/m^3 from burning charcoal dust of different tree species bonded with paper

Type of fuel briquette	$PM_{2.5}$ first Hr	$PM_{2.5}$ second Hr	$PM_{2.5}$ burning period of fuel
CD+Paper1A	268.9±5.7	259.8±3.3	262.5±2.7
CD+Paper2	294.9±75.7	103.9±0.6	180.1±34.2
CD+Paper3	51.8	49.4	50.7±0.7
LSD ($p<0.05$)			55.7
$P<0.05$			0.001

Tree species from which sawdusts were sourced influnced the IAC of $PM_{2.5}$(Table 6.9).IAC of $PM_{2.5}$ from raw sawdust fuel briquettes in *Cupressus lusitanica* (Sawdust+GA3) was lower than that from *Pinus patula* (Sawdust+GA2). Njenga et al., (in press) reported that IAC of $PM_{2.5}$ from *Grevillia robusta* raw sawdust bonded with gum arabica fuel briquette by a community group was 123000 µg/m^3. This was higher than the 27568µg/m^3measured from the experimental *Grevillea robusta* raw sawdust (Sawdust+GA1) fuel briquette. This data was not included in the analysis table above as data from its counterpert carbonized *Grevillea robusta*raw sawdust (Csawdust+GA1) was missing.

Table 6.9. Indoor air concentration of fine particulate matter ($PM_{2.5}$) in µg/m^3 from burning raw and carbonized sawdust fuel briquette bonded with gum arabica

Type of fuel briquette	$PM_{2.5}$ first Hr	$PM_{2.5}$ second Hr	$PM_{2.5}$ burning period of fuel
Sawdust+GA2	7355.9±2767.2	NA	7355.9±2767.2
Sawdust+GA3	NA	NA	3343.6±1649.8
Csawdust+GA2	120.4±39.7	99.9	157.7±29.72
Csawdust+GA3	67.0±16.6	30.0	44.3±7.3
LSD ($p<0.05$)			3400
$P<0.05$			0.001

CD=charcoal dust, GA=gum Arabica, Csawdust=carbonized sawdust, ± is standard error.

Reducing amount of gum arabica in production of raw sawdust fuel briquettes improved the IAC of $PM_{2.5}$ as was the case with CO. Carbonizing raw sawdust reduced IAC of $PM_{2.5}$ by 98% and could be associated with a reduction in volatile matter as was the case with CO.Therefore, adopting appropriate techniques such as carbonizing raw sawdust and using appropriate amount of binder in fuel briquette production will be beneficial to human health in respect to illnesses associated with indoor air pollution from CO and $PM_{2.5}$. However, there is a need to assess the effects of such practices such as reducing gum arabica quantities in sawdust fuel briquette production on other characteritics, such as durability and bulk density which are important in the handling and tranportion of fuel briquettes. There is also a cost implication in carbonizing sawdust where, for instance, the biomass conversion efficiency by weight was 40%. 35 kilograms of firewood from the ornamental *Chorisia speciosa* was used to produce 8 kilograms of carbonized sawdust (Maundu and Tengnas, 2005).

Fuel briquettes made from raw sawdust caused higher IAC of$PM_{2.5}$ than those made from charcaol dustsand these findings are in line with the study by Njenga et al., (2013) on fuel briquette made by community groups from charcoal dust and sawdust in Nairobi and sorroundings.

6.3.2.3 Carbon dioxide (CO_2) indoor emissions

All the fuel briquette types and the unprocessed charcoal produced high amounts of CO_2 during initial combustion stage, which was similar to observations with CO and $PM_{2.5}$. Use of soil, paper, gum arabica and cowdung as binders in production of fuel briquettes from charcoal dust resulted in emissions of 78.93ppm, 71.1 ppm, 139.5 ppm and 124.7 ppm of CO_2 respectively, which were significantly different at ($p<0.05$). Cow dung and gum arabica were poor binders compared to soil and paper with respect to IAC of CO_2 (Figure 6.3a). This may have been caused by the high volatile matter present in cowdung and gum arabica which was 55% and 85% respectively compared to 18% measured in soil.

The type of wood from which sawdust was sourced had no significant effect on IAC of CO_2 produced from fuel briquettesmade from sawdust (Figure 6.3c.).The amounts of CO_2 measured from experimental fuel briquettes made from *Grevillia robusta* raw sawdust was similar to 115.8 ppm measured during the burning period of one hour from *Grevillia robusta* raw sawdust fuel briquettes made by a community group as reported by Njenga et al., (2013). Raw sawdust fuel briquettes when compared with carbonized sawdust fuel briquette from similar tree species led to no significant difference ($p>0.05$)(Figure 6.3c.).

Type of tree species from which charcoal dust and sawdust are obtained, varying amount of gum arabica used as a binder in production of raw sawdust fuel briquettes and carbonizing sawdust before producing fuel briquettes all have no significant influence on IAC of CO_2 from burning fuel briquettes.

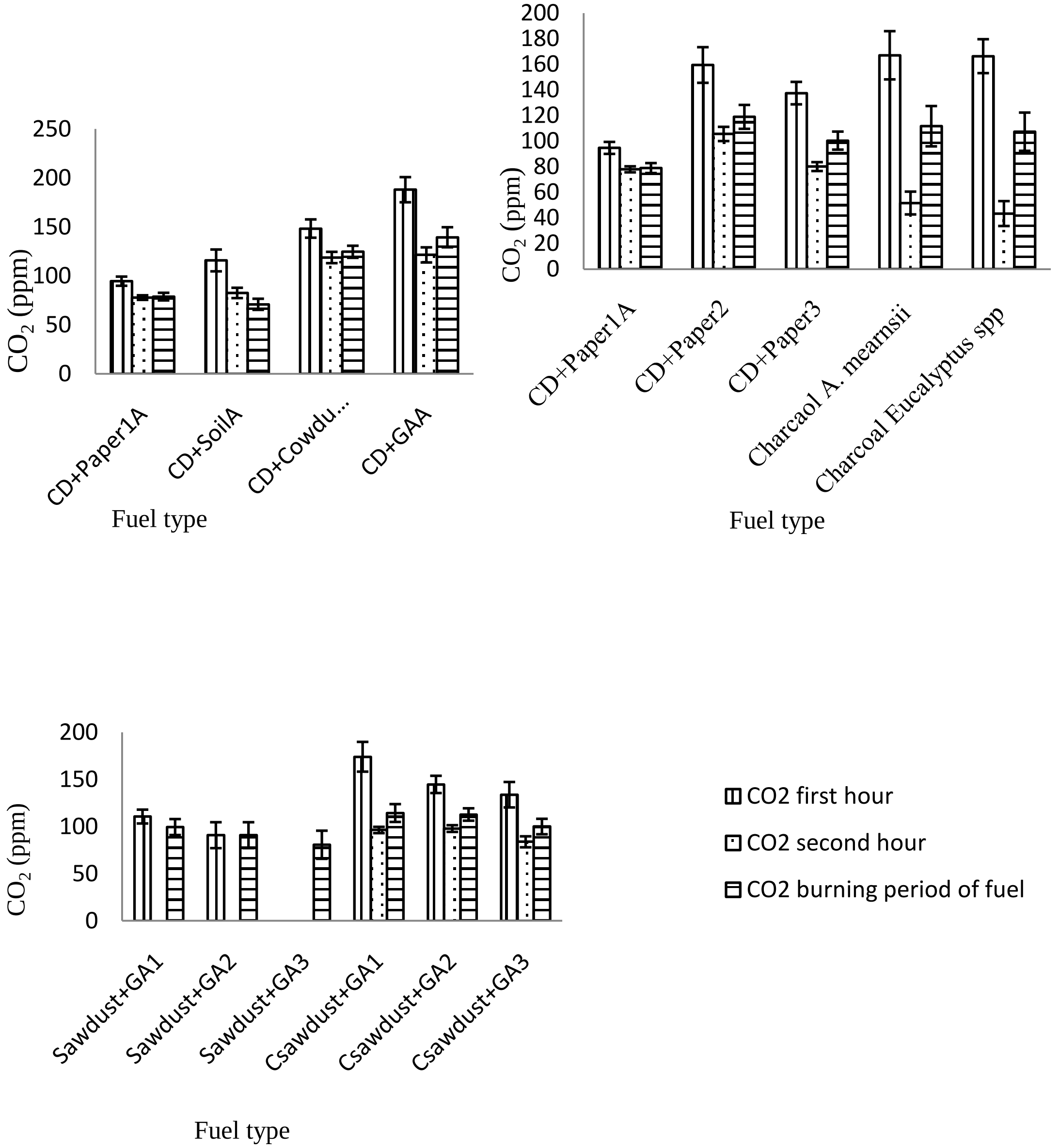

Figure 6.4a-c. Indoor air concentrations of carbon dioxide in the first hour, second hour and during burning period of fuel briquette and charcoal.Values are means of 3 replicates. CD=charcoal dust, Csawdust=carbonized sawdust.

6.4. CONCLUSIONS

Type of binder used influenced combustion properties of fuel briquettes made from charcoal dust. Gum arabica and paper performed the best in respect to calorific value and ash content while soil resulted in a longer burning period and lower IAC of CO and $PM_{2.5}$. Reducing gum arabica improved IAC of CO and $PM_{2.5}$ of raw sawdust fuel briquettes without a negative effect on calorific value. There is however a need for further research to find out whether reducing gum arabica has any effects on the physical properties of raw sawdust fuel briquettes. Type of tree species from which charcoal dust and sawdusts were sourced influenced the calorific value of fuel briquettes as well as IAC of $PM_{2.5.}$ When considering a combination of combustion and emissions properties, charcoal dust bonded with soil gives the best briquette. Raw sawdust briquettes had higher $PM_{2.5}$ than charcoal briquettes. As such raw sawdustbriquette could be more suited for industrial use such as drying tea, which is currently dried in the country using firewood. However,the challenge of high emission $PM_{2.5}$ from raw sawdust fuel briquette can be reduced throughcarbonizing sawdust before producing fuel briquettes and there is a need to assess both the costs and environmental implications of this treatment. When compared with the briquettes produced by local communities, the experimental fuel briquettes showed that there is need for technical and financial support on techniques that will help improve the quality of community products. This knowledge on quality improvement is likely to be applicable in many different parts of the world.

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CHAPTER 7: LIFE CYCLE ASSESSMENT (LCA) OF CHARCOAL BRIQUETTE FOR HOUSEHOLD COOKING IN KENYA

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ABSTRACT

Rising energy requirements is one of the major challenges facing the world today. Charcoal is a principal fuel in Kenya which provides energy for 82% of urban and 34% of rural households. Faced with the challenges of poverty, unemployment and access to affordable cooking fuel many poor households turn into briquette making. To provide cooking energy from a range of sources to meet people's needs will require adequate, reliable and affordable supplies that result in minimal impact on the environment. This paper presents a Life Cycle Assessment (LCA) of charcoal briquette for cooking a meal for a standard household of five people.Native vegetation of *Acacia drepanolobium* and low efficiency kiln for wood carbonization was considered as the common practice while *Acacia mearnsii* plantation and high efficiency kiln was used alternative scenario. Charcoal and kerosene were considered as reference fuels. Wood production from A*cacia mearnsii* plantation yields 5.5 times more fuel per hectare per year than *Acacia depanolobium* native vegetation.High efficiency kiln yield charcoal 2.4 times higher than low efficiency kiln. Recovering charcoal dust for charcoal briquette result in supply of an additional 16% of cooking fuel. Wood carbonization and cooking stage of the charcoal and cooking stage of charcoal briquettes caused the highest global warming potential (GWP). There is urgent need for technologies to improve efficiency in wood carbonization and household use of charcoal briquettes and charcoal. Supplying energy and cooking a traditional meal with charcoal briquettes and charcoal accounts for 1.3 and 4.9-6.3 kg CO_2e. per meal respectively if forests are not regenerated. These amounts decline to 0.18 and 1.9 kg CO_2e. per meal for charcoal briquette and charcoal when carbon dioxide from carbonization and cooking stages is taken up by regrowing biomass. This calls for replanting of trees cut down for charcoal and selection of tree species that naturally regenerate and those that coppice well if the neutral impact of biomass energy on GWP is to be maintained.

Keywords: charcoal briquette, charcoal, life cycle, cooking fuel, Kenya

7.1. INTRODUCTION

Rising energy requirements is one of the major challenges facing the world today. About 2.4 billion people use solid biomass fuels as a source of energy for cooking and heating (Kaygusuz, 2011). Charcoal is a principal fuel in Kenya (Karekezi, 2002) which provides energy for 82% of urban and 34% of rural households (MoE, 2002). Kituyi (2004) argues that for the short and medium terms, any sustainable development solutions in the household energy sub-sector in Africa must necessarily focus on biomass energy technology development and dissemination. Kerosene is used by approximately 92% of all households mainly for lighting and most of it produced at a refinery in Mombasa.

Eighty six per cent of Kenya’s charcoal producers source wood from private farms either owned individually or communally while the rest is from Government or county council land. Most of these charcoal sources are woody savannahs that constitute over two thirds of country’s area (MoE, 2002; Mutimba and Barasa, 2005). The wood found in the dry savannahs is usually hard and dense with low moisture content yielding good quality charcoal. Charcoal is produced by heating fuelwood (or any other raw materials) in some type of kiln with limited access to air, a process called carbonization which creates a fuel of higher quality than the original fuelwood (Pennise *et al*., 2001). Most charcoal producers use traditional earth kilns, which are cheap as they only require labour to construct. On the other hand they have low efficiency in converting wood to charcoal (Mutimba and Barasa, 2005; Okello, 2001). There are improved kilns with higher efficiency and better charcoal quality, but improved production techniques requiring more labour and cost (Odour *et al*., 2006).

Because of inherent inefficiencies in the carbonization process, there is substantial loss of carbon and energy from starting fuelwood primarily as carbon dioxide (CO_2) but also products of incomplete combustion (PIC) such as carbon monoxide (CO), methane (CH_4), particulate matter (PM) and oxides of nitrogen (Pennise *et al*., 2001). CO indirectly affects global warming through atmospheric photochemical reactions that in turn affect GHG levels. CH_4 and CO have higher global warming potential per kilogram of carbon, than CO_2 (Pennise *et al.*, 2001). Emission of many GHG from cooking stoves isthe result of the significant portion of fuel carbon that is diverted to PIC as a result of poor combustion inefficiencies (Edwards *et al*., 2003).

Faced with the challenges of poverty, unemployment and access to cooking fuel many poor households turn into briquette making. In Kenya, like in many developing countries, briquette production is focused on providing good quality cooking fuel. In the slum Kibera, Nairobi, 70% of householdsliving within 250 metres radius of a briquette production site, used charcoal briquettes which contributes to saving over 50% cost for cooking fuel (Njenga *et al.*, 2013). Briquettes are mainly used as substitute or compliment to charcoal as both use similar cook stoves (Aya *et al*., forthcoming). Half of the briquette enterprises in Kenya use charcoal dust as the main raw material sourced from charcoal sellers in urban areas and forms 10-15% of charcoal supply chain. Fifty per cent of briquetting activities are by community based groups and Nairobi city hosts half of them (Terra Nuova *et al*., 2007). To provide cooking energy from a range of sources to meet people's needs will require adequate, reliable and affordable supplies that result in minimal impact on the environment (Olz, 2007). It is therefore important to establish the potential environmental impacts of charcoal briquettes using science based tools such as Life Cycle Assessment (LCA). This will inform decision making in development of sustainable cooking biomass fuel to meet one of the greatest Africa's sustainability challenges-energy insecurity. Kituyi (2004) recommends that applying Life Cycle Management (LCM) in the charcoal supply chain in Kenya can deliver social, economic and environmental benefits to developing country communities and should, therefore, be promoted. A previous study on emissions from charcoal making in Kenya, recommended a full analysis of charcoal life cycle that includes evaluation of its final end use in combustion in cook stoves (Pennise *et al*., 2001). In another LCA on charcoal, biogas and liquid petroleum gas (LPG) in Ghana by Afrane and Ntiamoah (2011), global warming and human toxicity were the most significant overall environmental impacts associated with them, and charcoal and LPG, respectively, made the largest contribution to these impact categories. The current study was carried out to address the above mentioned knowledge gaps including determining emission factors of cooking using charcoal briquettes, charcoal and kerosene in Kenya to assess theirGWP. The resource use, in terms of wood and land required for wood production, for charcoal and charcoal briquettes from different production systems was also assessed. One objective was to quantify the environmental benefits of using charcoal dust, previously considered as waste, to produce briquettes and use as a fuel source.

7.2. MATERIALS AND METHODS

The study was carried out in accordance with the ISO 14044 (2006) that specifies requirements and guidelines for conducting LCA(Buamann, H, Tillman, A.M., 2004) which are described under materials and methods in chapter 3.

7.2.1 Goal and scope of the study

7.2.1.1 Goal, functional unit and comparisons made

The goal of the study was to establish potential environmental impacts of charcoal briquette as a cooking fuel in its different stages of current production and use system in Kenya. The LCA aimed at identifying stages that requires technological and policy interventions in the life cycle of charcoal briquettes towards its development as a sustainable cooking fuel. The other aim was to establish emission factors (EF) for carbon monoxide (CO), carbon dioxide (CO_2) and fine particulate matter ($PM_{2.5}$) from household cooking with charcoal briquettes, charcoal and kerosene. The functional unit in this study was amount of fuel used in cooking a traditional meal -a mixture of 500 grams of green maize (*Zea mays*) and 500 grams of dry common bean (*Phaseolus vulgaris*) commonly known as G*itheri* for a standard Kenyan houehold of five people (Kenya Government, 2010). Climate impact as $GWP_{100}$was calculated in kg CO_2 equivalent (CO_2e) per meal using SimaPro software (SimaPro 7.3.3, 2011). Global-warming potential (GWP) is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide. GWP is calculated over a specific time interval, commonly 20, 100 or 500 years. GWP is expressed as a factor of carbon dioxide whose GWP is standardized to 1 (IPCC, 2007). Data used in the life cycle was based on own measurements, literature values and the Ecoinvent database inbuilt in the SimaPro grogram (Ecoinvest Centre, 2010; SimaPro 7.3.3., 2013). The distinct processes in the LCA include common practices of sourcing wood from *Acacia drepanolobium* native woodland savannas, wood carbonization using low efficiency earth mound kiln, transportation of charcoal to urban areas and use of charcoal briquette in cooking (Figure 7.1). The studyalso makes comparisons with improved practices such as wood production in *Acacia mearnsii* plantation and wood carbonization using high efficiency mound kiln. It further compares cooking the standard meal with two reference fuels; charcoal and kerosene.

7.2.1.2 System description

(a) Studied Scenarios

The two scenarios that were looked at were;

i. Common or traditional system: *Acacia drepanolobium* native woodland savannas and low efficiency carbonization process and the
ii. alternative or improved system: *Acacia mearnsii* plantation and high efficiency carbonization process

(b) Wood production

Two wood production systems, an *Acacia drepanolobium* woodland savanna system and an *Acacia mearnsii* plantation system were compared under two different assumptions. Firstly, it was assumed that wood production was not renewable, that biomass would not regrow. Secondly, wood production was assumed to be renewable and carbon neutral based on the natural vegetation regrowth. The life cycle assessment (LCA) considered production of wood of native vegetation of *Acacia drepanolobium* in a private farm as the common practice (Figure 7.1.). *Acacia drepanolobium* is an ideal candidate for sustained charcoal production because (a) it occurs in almost mono-specific stands in high densities over vast areas, (b) it coppices readily when harvested or top killed by fire, (c) it's hard wood makes good quality charcoal and (d) income from its charcoal is an attractive source of supplemental revenue. Under the *Acacia depanolobium* woody savannas, charcoal producers harvest mature stems and leave the young ones to grow from the same plant. This native vegetation system was compared with production of wood from plantation of *Acacia mearnsii* as the improved case. Under the *Acacia mearnsii* plantation system mature stems are harvested and the young ones left to grow for next harvesting and the land is always covered by vegetation. In the native vegetation and plantation systems a 14 and 9 year rotational cycles were considered with biomass yield of 18.3 tonnes per hectare (t/ha) and 65 t/ha respectively (Okello *et al*. 2001; Cheboiwo and Mugo, 2011). Wood is harvested manually and transported by humans to the carbonization site using wheelbarrows in both systems.

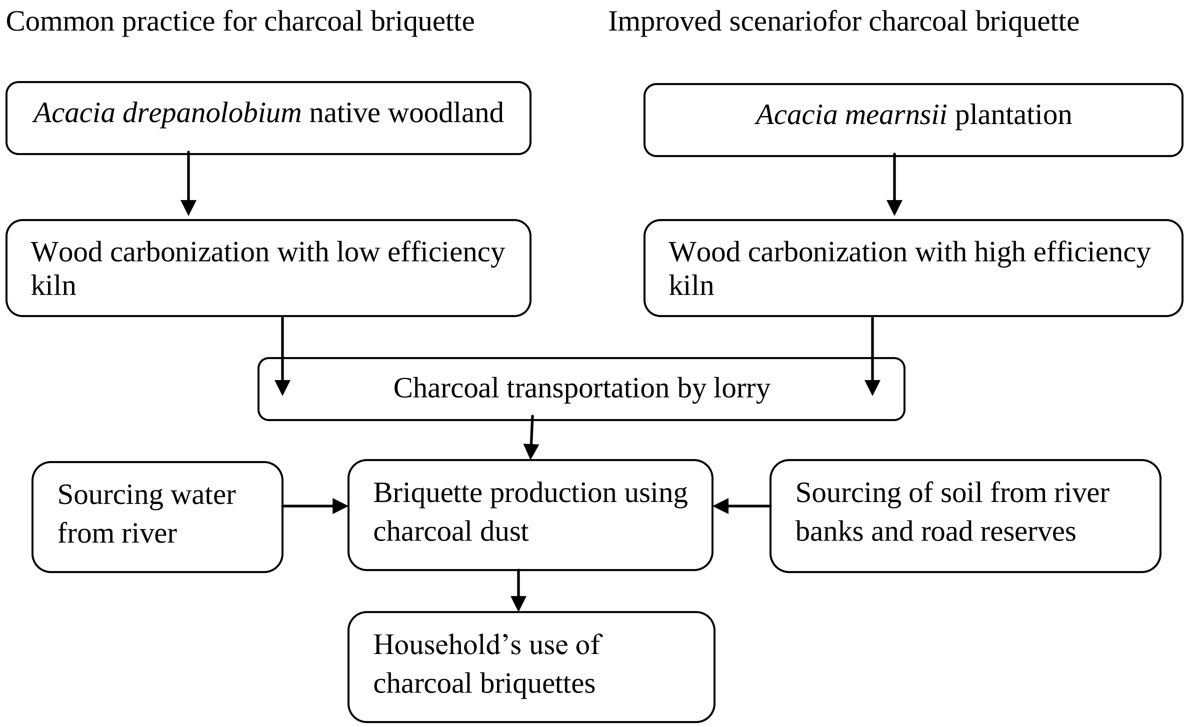

Figure 7.1 Flowchart of charcoal briquette production and use in Kenya.

In the case of charcoal as a reference both scenarios on the current practices and improved were considered as shown in figure 7.1 up to transportation of charcoal. After that charcoal is used as cooking fuel and charcoal dust is burned in the open at the charcoal trading places.

(c) Wood carbonization and transportation of charcoal

To determine the amount of wood required to be carbonized into charcoal to cook a traditional meal, traditional earth mound kiln with efficiency in yield of 14% dry mass was assumed as it is the most common practice used by charcoal producers in the country (Okello *et al*, 2001; Mutimba and Barasa, 2005; Figure 2a). Traditional kilns are favoured across sub-Saharan Africa because they require very little capital investment, are flexible in size and shape, and are well-matched to the dispersed nature of the charcoal trade (Mugo and Poulstrup, 2003).

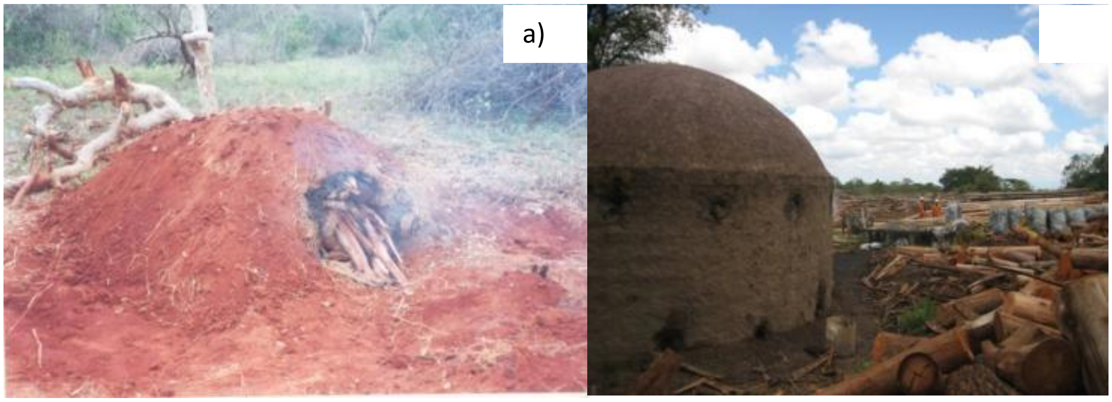

Figure 7.2 (a) Low efficiency earth mound kiln (Photo by Nelly Odour) (b) Masonry high efficiency improved mound kiln

In comparison a high efficiency mound kiln called Masonry with an efficiency of 33% being used by Kakuzi Ltd and former EATECH Eldoret was considered (Kakuzi, 2003; Figure 7.2.b). After charcoal is produced it is packed in recycled sacks originally used to pack produce such as sugar, maize and maize flour. Each sack contains about 40 kg of charcoal (PISCES, 2011).Transportationof charcoal from the production site to the road is done using donkey carts which were not included in the calculation. Transportation to Nairobi city one of the major consumers of charcoal was taken as 200 kilometres which is the radius for sources of charcoal such as Narok, Machakos, Laikipia and Kajiodo. A lorry of *lorry 3.5-7.5t, EURO3/RER S* was selected from Ecoinvent database. The kg CO_2ewas calculated per amount of fuel used to cook the meal per kilometre.

(c) Waste management of charcoal dust and its recycling into charcoal briquettes

Charcoal dust which comprises 10-15% (an average of 13% assumed) along the Kenyan charcoal supply chain is mainly found at the charcoal selling places and is burned or disposed of in open drainages (Mugo *et al*., 2007). In the charcoal briquette case, the charcoal dust is used in charcoal briquette production (Figure 7.1). In the charcoal reference case, burning was considered as the common practice of managing this waste and emissions assumed to be the same as those emitted during burning of charcoal in a kitchen as described below. The studied charcoal briquette represents a type that is made by community groups in Nairobi. The local people mix charcoal dust with soil at a proportion of 20% dry weight as a binder and add water to make slurry. The slurry is then mounded by hand in a recycled plastic can to shape it and squeeze out water and later dried in the sun. Briquettes production methods adopted by local communities in Kenya are described by Njenga *et al*., (2013). Soil was assumed to be inert as the soil used is subsoil, for example found as waste from dug pits, roadsides and riversides. Water is fetched from natural shallow wells and transported on foot and this process is excluded from this LCA.

(e) Kerosene production and transportation

Kerosene was the other type of cooking fuel used as reference. Its production stage was considered at the refinery in Mombasa and data from Ecoinvent database on *Kerosene, at refinery/RER U* was used. *Electricity, hydropower, at power plant/SE U* was chosen as it is the common source of power in Kenya. Data on transportation using *Lorry greater than 16t, fleet average/RER S* was chosen from the Ecoinvent database. Kerosene is transported to Nairobi from the refinery in Mombasa a distance of 500 km. The distance was doubled as the trucks are driven back to Mombasa empty and kg CO_2ewas calculated amount of fuel used in cooking the meal per kilometre.

(f) Use of the three types of fuel for cooking

Real time mesurements were made on amounts of *Acacia mearnsii* charcoal, charcoal briquettes and kerosene used in cooking the traditional meal for a standard Kenyan household of five people. The cooking efficiency tests were carried out at the Human Needs Project (HNP) open ground at Kibera slum, Nairobi in early 2012. The amount of fuel used and time taken to cook the meal were calculated. The cooking was conducted by 23 women who lit the cook stoves, added water and fuel as required and tasted when the food was completely cooked. Eight hundred and fifty grams of charcoal briquette, 890 grams of wood charcoal and 0.36 liters of kerosene were used separately to cook the strandard meal. Cooking with charcoal briquette and charcoal was done using the commonly used improved cook stove known as Kenya Ceramic Jiko (KCJ) and for kerosene, the cook stove from India used in Kenya was used.

Indoor air concentrations of CO, CO_2 and fine PM $_{2.5}$ were measured from burning charcoal briquettes and charcoal that filled the small-sized Kenya Ceramic Jiko (KCJ) and kerosene in a kerosene stove as practiced by households: 0.75 kilograms of charcoal briquettes and 0.64 kilograms of wood charcoal and 0.1 litres of kerosene.

7.2.1.3 Allocation

Allocation of burden between pure charcoal and charcoal briquettes at the wood carbonization and transportation stages were assumed to be zero for the latter as most charcoal dust is not used and is considered as waste with no value. This allocation was made according to procedure described by Baumann and Tillman (2004).

7.2.1.4 Data management and analysis

The calculations of kg CO_2 equivalent (CO_2e) on wood carbonization applied emission factors of traditional earth mound kilns in Kenya from work by Pennise *et al*., (2001). The emission factors for the above mentioned wood carbonization processes were used as presented in table 7.1.

Table 7.1. Emission factors, grams of pollutant per kilogram charcoal produced

Description of efficiency	Type of kiln	CO_2	CO	CH4	NO_*
Low efficiency (22%) earth mound kiln	EM1, EM2	2510	270	40.7	0.1085
High efficiency (33%) earth mound kiln	EM4, EM4	1103	169	47.0	0.033

EM=traditional earth kilns. Source: Pennise *et al*., 2001

Data on indoor air concentrations of CO, CO_2 and PM $_{2.5}$ from cooking with charcoal briquettes, charcoal and kerosene presented in table 7.4. wereused to calculate emission factors by assuming full combustion of kerosene of known chemical composition. Data on amount of wood produced, selected mode of transport from Ecoinvent database and emission factors in wood carbonization, waste management of charcoal dust and cooking were entered per process and assembled at each stage of the product using SimaPro 7.3.3 software (SimaPro 7.3.3, 2011). The SimaPro 7.3.3 program was acquired through a temporal 6 months renewable Faculty License at no cost. SimaPro is easy to use and provides quick results. The program assists in managing complex tasks while all the results remain completely transparent. The program allows one to create a new project and enter data as well as select data from the inbuilt Ecoinvent database at every process and create files with all product stages from which the program is ran. Once the product stage file is ran, the program calculates Kg CO_2e at each process or stage of the product as well as total amount along the life cycle.There were challenges in finding data on transport and refinery based on Kenyan situations in the Ecoinvent database due to few number of LCA's in developing countries and use of data from Europe was the only option which was readily available in the Ecoinvent database. This challenge was also faced by scientists conducting an LCA on charcoal from sawmill residues in Tanzania (Sjolie, 2012).

Data was managed using Microsoft Excel software and analysed for descriptive statistics such as mean and standard deviation using the same sofware. Genstat Edition 13 was used for One Way Analysis of Variance (ANOVA) (VSN International 2012).

Significance difference between any two means was tested using the least significant difference of means (LSD).Actual probability values have been presented as ‘p’ to show significance at confidence level of 95%.

7.3. RESULTS AND DISCUSSION

7.3.1 Land requirement for wood production

A. drepanolobium native woodland vegetation yield 0.18 t/ha and 0.43 t/ha of charcoal per year when low and high efficiency kilns areused, respectively. Producing wood in *A. mearnsii* plantation system yield 1.01 t/ha and 2.39 t/ha of charcoal per year when low and high efficiency kilns are used, respectively. Between 0.03t/ha and 0.37 t/ha additional fuel per year was produced through recycling charcoal dust for briquette production (Table 7.2).

Table 7.2 Yield of fuel and number of meals per hectare in traditional and improved charcoal production systems

Wood production	*A. drepanolobium* native woodland		*A mearnsii* plantation	
Wood carbonization	Low efficiency (14%) kiln	High efficiency (33%) kiln	Low efficiency (14%) kiln	High efficiency (33%) kiln
Yield of biomass t/ha per year[a]	1.31	1.31	7.22	7.22
Yield of charcoal in t/ha per year	0.18	0.43	1.01	2.39
Number of meals from charcoal per ha per year	182.57	430.36	1011.11	2383.33
Additional fuel by charcoal briquette in t/ha per year	0.03	0.07	0.16	0.37
Additional meals by charcoal briquette per ha per year	33.50	79.00	185.56	437.33

[a] Biomass usable for charcoal production

There is efficiency gain by shifting from *A. drepanolobium* natural vegetation to *A. mearnsii* plantation (5.5 times) as well as from the shift from low efficiency kiln (14%) to high efficiency kiln (33%) (2.4 times). As a consequence, promotion of sustainable management of plantation for charcoal production is desirable such as through short rotation forestry. Farm forestry, including the planting of woodlots on farms for charcoal production, would go a long way in providing an on-going supply of raw materials (Kituyi, 2004). This improvement in wood production should be combined with adoption of high efficiency wood carbonization processes. It is however important to note that this direct comparison has shortcomings as the native vegetation in drylands is also used as grazing areas for livestock and wildlife.

The methods used in wood carbonization determine the amount of wood required and consequently the land required for wood production. To produce charcoal that cooks a meal, 3 and 7 kg, respectively of wood is required using high and low efficiency carbonization processes. This amount of wood includes 13% that ends up as charcoal dust. Adoption of improved methods will reduce wood and energy wastage hence less land requirement and saving of trees. Recovering charcoal dust for charcoal briquette production gives additional cooking fuel, between 0.40 and 3.35 t/ha, when traditional and improved systems are adopted. Hence charcoal briquette contributes 16 % and 18 % additional fuel and meals respectively per hectare, resulting in lower land demand for production of this type of cooking fuel. The higher percent increase in meals compared to increase in fuel yield is because less amount of fuel is used for charcoal briquette compared required pure charcoal. The number of meals from charcoal briquettes could be increased by carbonizing biomass unusable for charcoal production such as branches and leaves.

7.3.2 Global warming potential from production and use of charcoal briquettes and charcoal

Greenhouse gas emissions from producing energy and cooking a meal with charcoal from wood using high efficiency carbonization process resulted into a GWP of 4.9 kg CO_2e. which is 22% lower than the low efficiency wood carbonization system (Table 7.3). This is due to the higher wood demand in the low efficiency system;most of the emissions are generated from the wood carbonization. GWP in the producing and cooking with charcoal briquette was 1.25 kg CO_2e. which is 5 and 4 times lower than charcoal in high and low efficiency kilns respectively. An LCA of eucalyptus charcoal briquettesin Brazil by Rousset *et al*., (2011) showed that supplying the energy content of 1 kilogram (kg) of briquettes resulted in 4 kg of CO_2 emission. However, details on assumption for this emission werenot presented;it was only stated to be a sustainable eucalyptus plantation. In this study, the charcoal briquettes were made from waste, charcoal dust, whereas in the Brazilian study, the briquettes were the result of an industrial production process.

The kerosene life cycle resulted into GWP of 1.53 kg CO_2e. which is 3-4 times lower than charcoal and 1.2 times higher than charcoal briquette.

Table 7.3. Global warming potential (kg CO_2e.) in life cycles of charcoal briquette, charcoal and kerosene for cooking a standard traditional meal *(Githeri)* in Kenya

	Charcoal briquette		Charcoal		Kerosene
Stage	*Acacia drepanolobium* native woodland and low efficiency kiln	*Acacia mearnsii* plantation and high efficiency kilns	*Acacia drepanolobium* native woodland and low efficiency kiln	*Acacia mearnsii* plantation and high efficiency kilns	
Wood carbonization	0	0	3.87	2.45	NA
Refinery	[a]	[a]	[a]	[a]	0.48
Transportation	0	0	0.1	0.1	0.05
Waste management	0	0	0.3	0.3	[b]
Cooking	1.25	1.25	2.07	2.07	1.00
Total (non-renewable biomass)	1.25	1.25	6.34	4.92	1.53
CO_2 taken up by biomass	-1.07	-1.07	-4.39	-2.98	0
Total (renewable biomass)	0.18	0.18	1.95	1.94	1.53

[a]not applicable, [b]included in refinery

7.3.2.1 Traditional vis a vis improved wood carbonization methods

Due to its higher efficiency in converting wood into charcoal, the high efficiency kiln saves 57% of wood used in the low efficiency kilns to produce charcoal to cook the same size and type of a meal. These findings are in line with findings on resource use in charcoal production in Kenya and Tanzania using improved kiln vis a vis traditional ones (Bailis, 2009;Pennise *et al*., 2001;Kituyi 2004;Sjolie, 2012). This supports the on-going initiatives by organizations such as Kenya Forestry Research Institute (KEFRI) on development and use of more efficient wood carbonization processes in the country (Oduor *et al*., 2006). This will yield more charcoal from each kilogram of wood. This data is also useful in reinforcement of regulations for sustainable charcoal sector in Kenya which recommends use of efficient wood carbonization processes governed by the Kenya Forest Services (Gathui *et al*., 2011). At the wood carbonization stage, using high efficient kiln reduced GHG emissions by 37% when compared to low efficient kiln (Table 7.3). The lower the contribution of this stage to GWP in the product life cycles with higher efficiency in carbonization processes. In respect to GWP, carbonization process rank higher than cooking which is discussed later in terms of environmental impacts. There is no environmental blame allocated to charcoal briquette in this stage as the charcoal dust is not used and is considered as waste.

7.3.2.2 Transportation of the three fuel types and production of kerosene

Transportation of charcoal that cooks a standard meal from rural areas to the city results into 0.1 kg CO_2e. whiletransporting charcoal dust that produces charcoal briquettes accounts for zero burden as it is considered as waste. Packing of charcoal was excluded from the calculations because recycled bags are used. GWP caused by transportation of charcoal could be reduced through peri-urban agroforestry that would contribute to shorter distances to urban centres. Kerosene production stage caused GWP of 0.48 kg

CO_2ewhile its transportation to the city caused 0.05 kg CO_2e., accounting for 31% and 3% respectively of the life cycle. There was lower kg CO_2e. from transporting kerosene than transporting charcoal which could be associated to use of larger vehicles in the former.

7.3.2.3 Management of charcoal dust at charcoal selling places

In the absence of recycling charcoal dust for briquette making it is either burned on site or thrown into open drainages. Handling charcoal that cooks the traditional meal results in 0.13 kg of charcoal dust and burning it in urban areas produces 0.3 kg CO_2e (Table 7.3). This implies that recycling charcoal dust for briquette production contributes to mitigating climate change through reduced global warming that otherwise result from burning this type of waste.

7.3.2.4 Emissions from cooking with different fuels

Using charcoal briquettes for cooking emitted the lowest amounts of CO_2, CO and $PM_{2.5}$ (Table 7.4). There was a significance difference at $P<0.05$ in CO_2, CO and $PM_{2.5}$ among the three types of fuels. Cooking with charcoal briquettes compared to charcoal reduced CO_2, CO and $PM_{2.5}$ emissions by60%, 72% and 88% respectively. Charcoal had the highest emission factors of CO_2, CO and $PM_{2.5}$ and there was a significance difference at $P<0.05$ in CO_2 and CO among the three types of fuel.

Table 7.4.Indoor air concentration of CO_2, CO and $PM_{2.5}$ and emission factorsin grams of pollutant per meal in household cooking.

Type of fuel	Burning period (hour)	Amount of fuel burned	Amount of fuel per meal	Average indoor air concentration during cooking			Emission factors in grams of pollutant per meal		
				CO_2 (ppm)	CO (ppm)	$PM_{2.5}$ (mg/m^3)	CO_2	CO	$PM_{2.5}$
Charcoal briquette	4	0.75 kg	0.85 kg	96.6	16.4	0.04	1069.7	115.8	0.2
[a]SD				17.3	1.7	0.03	191.7	11.8	0.1
Charcoal	2.5	0.64 kg	0.89 kg	240.6	59.1	0.37	1665.0	260.3	0.9
SD				25.2	5.4	0.2	174.1	24	0.7
Kerosene	1	0.1 l	0.36 l	271.9	37.7	0.3	752.8	66.3	0.5
SD				53.6	11.1	0.07	148.4	19.5	0.1
[b]LSD ($p \leq 0.05$)				71.1	14.4	0.2	344.3	38.2	0.9

[a]Standard deviation (SD) and least significant difference ([b]LSD).

At the cooking stage, using charcoal briquette reduced global warming potential 2.3 times from cooking with charcoal (Table 7.2). Cooking stages of charcoal and charcoal briquettes had the highest global warming potential compared to other stages of their life cycles (Table 7.3). Cooking with charcoal briquettes accounted to 100% of GWP in its life cycle as other stages as shown in table 7.3 were considered to have no environmental burden as its raw materials are waste in the charcoal supply chain.

Cooking with kerosene caused GWP of 1.0 kg CO_2e accounting for 65% of its life cycle emissions. Cooking with kerosene caused a reduction in GWP of 2 times and 1.3 times when compared to charcoal and charcoal briquettes, respectively, in the case of non-renewable wood sourcing. However, cooking the traditional meal with kerosene costs 45 ksh (US$0.6) which is 2 and 6 times higher than charcoal (Ksh26 and US$0.35) and charcoal briquettes (Ksh3 and US$0.04), respectively (Njenga *et al*., 2013). Cooking with kerosene also requires cooking appliances that the poor might not afford.

Emissions from cooking are not only providing GHG emissions, but also have large health impacts. Cooking is also a stage where fuel efficiency as well as emissions may be influenced by the type of cook stove used (Edwards *et al*., 2003). For intance use of improved Kenya Ceramic Jiko (KCJ) as opposed to the traditional type for cooking reduced emission of CO by 15% (Kituyi *et al*., 2001). Hence fuel efficiency and emissions and consequently the life cycle GWP may differ from one household to another depending on type of cook stoves used. To address GWP caused by cooking, there is need for urgent technological and policy interventions to reduce emissions at this stage such as adoption of efficient cook stoves. There is also need to assess the health implications of cooking with the three studied fuels.

7.3.2.5 Carbon dioxide (CO_2) uptake by biomass

If wood used for charcoal and charcoal briquette production comes from forests that regrow after wood harvesting, CO_2 emitted will be taken up in regrowing vegetation (Table 7.3). In this case, the GWP from charcoal briquettes would be reduced to 0.18 kg CO_2 eq. per meal, which is much lower than for charcoal and kerosene, which were similar at 1.9 and 1.5 kg CO_2e per meal, respectively (Table 7.3). In this case a major source of GWP in the charcoal life cycle was methane from wood carbonization. This and other emissions in the life cycle of charcoal arelarge enough to give a higher GWP from charcoal than kerosene, even when the wood production is renewable.

Wood carbonization and cooking stages were the main processes contributing to GWP from charcoal briquette and charcoal life cycles, but a large part of this was in the form of CO_2 from biomass combustion. Hence uptake of kg CO_2e by biomass from these significantly declines the total enviromental burdens by cancelling most of the emissions from these two types of fuel (Table 7.3). This emphasises the importance of replanting trees cut down for charcoal, use of mature stems leaving others to grow from the same tree, chosing tree species that coppice well and those that naturally regenerate. It is equally critical to recommend suitable species in different agroclimatic conditions. For instance the studied *Acacia mearnsii* grows well in Agroclimatic zones I-III (Maundu and Tengnas, 2005). It is suited for woodlots and should not be intercropped as it competes for nutrients and should be well managed as it is potentially a weed. It is important to also ensure recommending tree species that do well in the naturally dry conditions, such as *Acacia tortilis* for agroclimatic zones (IV-VII) (Maundu and Tengnas, 2005).

Recent developments in GHG balances of bioenergy systems have shown that assumptions about forest carbon cycles have large impacts on the resulting GHGs (Helin *et al*, in press). As our analysis is focused on later stages in the life cycle, not on primary production of biomass, the forest carbon cycles have not been described or analyzed in detail. However, our systems limitations and assumptions contain some implicit assumptions about carbon cycles. In the charcoal and charcoal briquette scenarios, it was assumed that there were no changes in soil C or vegetation C. Only CO_2 uptake from harvested biomass was included, which is an implicit assumption that there is no net uptake or loss of C in soils or vegetation in these forest systems. This is a simplistic assumption, and better knowledge about C cycling in forest ecosystems and plantations in Kenya could shed light on this issue and show if other assumptions would better describe the current situation (Bailis, 2009). Furthermore, in the fossil fuel reference case, when kerosene is used as fuel, no assumption was made on CO_2 uptake or emissions from land use. This is equivalent to assuming no change in C stock due to land use, i.e. no net growth of forest. This could be the case in a mature forest or a degraded forest with no re-growth. An alternative assumption could have been to assume that if kerosene was used instead of charcoal, there would be a regeneration of biomass in forests, i.e. a net uptake of CO_2. That would give the kerosene system a lower GWP than with our original assumptions.

The carbon neutral forest systems described include a regeneration period of 9 years for *Acacia mearnsii* plantation and 14 years for *Acacia drepanolobium*. During that period, CO_2 emitted by biomass is gradually taken up by regrowing biomass, but the CO_2 spends some time in the atmosphere and contributes to GWP during that time. Previously, this has not been included in LCAs, but such omission has been questioned in recent years, and different methods to account for this CO_2 dynamics has been suggested (Helin *et al*, in press). A simple method for accounting for this the climate impact of biogenic CO_2 is the GWP-bio index proposed by Cherubini *et al.*, (2011).

7.4. CONCLUSIONS AND RECOMMENDATIONS

Recovering charcoal dust for charcoal briquette production, contributes with additional fuel, which improves energy security and may save trees and hence preserve a carbon sink and reduces deforestation. Cooking food with charcoal briquettes had low GWP_{100} as compared to charcoal as the former is made from waste from the latter's production process and also because the former burns cleaner. Charcoal briquettes, but not charcoal, had lower GWP than kerosene. Wood carbonization and cooking stages of the charcoal and charcoal briquettes caused the highest GHG emissions along the life cycles of these two types of biomass cooking energy. Adopting improved wood production and wood carbonization systems will result in additional cooking fuel supply and reduced GWP. It is critical for households to adopt technologies that increase fuel efficiency and reduce emissions from cooking with charcoal, charcoal briquettes and kerosene. Although kerosene had lower GWP than charcoal, its adoption among the poor is a challenge following its high costs and cost of appliances used for cooking. For sustainability in supply of charcoal briquettes and charcoal as cooking fuels in developing countries, there is urgent need for adoption of short rotational agroforestry with right species for different agroclimatic zones. It is crucial to replant trees cut down for charcoal and to select tree species that regenerate naturally and those that coppice well to ensure presence of biomass for uptake of carbon dioxide hence maintaining the neutral impact of biomass energy on GWP.

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CHAPTER 8: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

8.1 SUMMARY

As presented in chapter 4, community based fuel briquetting enterprises contribute to improving livelihoods of urban poor through generating income through sales, savings between 70-30% made on cooking energy by producing fuel briquettes for own use or through purchases and creation of employment. These findings address objective three of the study on socio-economics implications of fuel briquette technology. Local production of fuel briquettes in Nairobi and environs used charcoal dust bonded with either soil or paper and sawdust bonded with gum arabica. The communities used either metal or wooden manual presses or pressed using hands in recycled plastic cans while sawdust briquettes were produced using manual metal presses as presented in chapter 5.

Type of raw material and production methods used in fuel briquette production, influenced combustion and emission properties of the product. For instance locally produced charcoal dust briquettes bonded with paper had calorific valuesbetween 21kJ/g and 19kJ/g,while those produced using charcoal dust bonded with soil ranged between 14kJ/g and 15kJ/g. Sawdust bonded with gum arabica had a product with 20kJ/g. Calorific value of the experimental fuelbriquettes made from charcoal dustbonded with paper was 25kJ/g, while that of charcoal dust from *Acacia mearnsii*,*Eucalyptusspp* and A. *xanthophloea* was 27kJ/g and 26kJ/g, respectively. Calorific value of experimental fuel briquettes made from*Acacia mearnsii*charcoal dust bonded with soil, cowdung and gum arabica was 25kJ/g, 23kJ/g and 28kJ/g,respectively.In the experiments, fuel briquettes of sawdust bonded with gum arabica had calorific value of 20kJ/g, 14kJ/g and 18kJ/g for sawdust from *Grevillea robusta*, *Pinus patula*, and *Cupressus lusitanica* respectively.Emissions of CO, $CO_2$and $PM_{2.5}$of charcoal dust bonded with paper briquettes produced by local community were 25ppm, 90ppm and0.06mg/m^3, respectively.CO, $CO_2$and $PM_{2.5}$ of locally produced fuel briquette made from charcoal dust bonded with soil was 15ppm, 85ppm and 0.03mg/m^3,respectively.Locally produced fuel briquettes of sawdust bonded with gum arabica had CO, $CO_2$and $PM_{2.5}$of 27ppm, 116ppm and 0.26mg/m^3,respectively.Emissions of $PM_{2.5}$, from experimental fuel briquettes made from*Acacia mearnsii* charcoal dust bonded with paper, soil, cowdung and gum arabica was 0.3 mg/m^3, 0.2mg/$m^3$and 0.3mg/$m^3$and 0.08mg/m^3,respectively. In the experiments, fuel briquettes of sawdust bonded with gum arabica had $PM_{2.5}$of 28mg/m^3, 7mg/m^3 and 3mg/$m^3$for sawdust from *Grevillea robusta*, *Pinus patula*, and *Cupressus lusitanica*, respectively. While fuel briquette made using carbonized sawdust bonded with gum arabica had $PM_{2.5}$of 0.052mg/$m^3$and 0.04mg/$m^3$for sawdust from*Pinus patula* and *Cupressus lusitanica*, respectively. Fuel briquettes made from raw materials sourced from dumping sites had high heavy metal concentrationsuch as 85.7mg/kg of Cr measured in CD+Carton briquette compared to 3.4mg/kg in CD+Paper2 whose dust was sourced directly from charcoal traders. Other factors such as type of paper may have contributed to the concentrations of the heavy metals in fuel briquettes.

These results on heating value and emissions from fuel briquettes made by local communities and those produced in the experiments using different raw materials and binders addresses objectives one and two which were meant to assess the implication of production technologies on quality and test the first and second hypothesis. These findings are discussed in chapters five and six. In respect to climate change, supplying energy and cooking a traditional meal with charcoal briquettes and pure charcoal accounts for 1.3 and 4.9-6.3 kg CO_2e per meal respectively if forests are not regenerated. These amounts decline to 0.18 and 1.9 kg CO_2e per meal for charcoal briquette and pure charcoal when carbon dioxide from carbonization and cooking stages is taken up by regrowing biomass. These findings are presented in chapter seven and addressed objective four which sort to establish the potential environmental impacts of fuel briquettes and hypothesis three.

8.2 CONCLUSIONS

- Local communities press fuel briquettes using manual wooden or metal machines and bare hands.
- Fuel briquette technology has positive social economics benefitsby providing income through sales, savings on income spent on purchasing cooking energy,creation of employment and provision of clean affordable cooking fuel among poor urban households. These benefits contribute to women and youth empowerment who are the main fuel briquette producers. Women also benefit through savings that they use on other household needs such as food and health.
- Types of feedstock and mixing ratios between raw material and binders influence combustion and emission characteristics of fuel briquettes.Quality of fuel briquette is also influenced by type of tree species from which charcoal dust and sawdust are sourced which could be associated to characteristics of wood among other factors.

- Heavy metal contamination was higher in fuel briquettes made from raw materials and binders sourced from dump sites.
- Carbonizing sawdust for fuel briquette production enhances combustion and emission qualities of the product for instance by reducing content of volatile matter.
- Fuel briquettes produced through experiments had better quality than those produced by community based groups which could be associated to better mixing rations between raw materials and binders and fine grinding and homogenizing charcoal dust in the former.
- Charcoal briquette has lower GWP than pure charcoal and Kerosene as it is made from waste in the charcoal supply chain and has less emission when used in indoor cooking.

8.2 RECOMMENDATIONS

- Charcoal dust is the main raw material used in fuel briquette production in the city and its surroundings, and hence there is need to ensure its supply through addressing the sustainability in production of pure charcoal. This could be done through management of trees under short rotational forestry with appropriate species for different agroclimatic zones.Tree replanting and proper management will not only supply wood for charcoal production but will also ensure presence of biomass for uptake of carbon dioxide hence maintaining the neutral impact of biomass energy on GWP. Higher efficient biomass carbonization processes need to be developed and promoted. There is also need to diversify types of raw materials used in fuel briquettes production such as household and market organic waste.

- Train local communities would help them improve on the quality of their product. The trainings should be responsive to the needs of the different gender categories and focused on appropriate production methods such as correct mixing ratios of raw material and binder and carbonization of biomass materials for fuel briquette production. This then call for identification of cost effective and environmental friendly carbonization processes.
- Further research is required on suitability of charcoal cookstove for briquettes use, need for development of fuel briquette cook stoves and opportunities and constraints in their adoption. Studies should be conducted to evaluate the potential of fuel briquette in the carbon credit market while taking into account local communities as producers and users as well as integrating gender responsiveness.
- Studies on physical characteristics of fuel briquettes are important in handling and transportation.There is also need for research on potential of producing fuel briquettes from other sources of organic by-products such as household and market organic waste.
- For community based fuel briquetting to prosper and make full impact, central and local government authorities need to provide assistance to these types of small enterprises, enabling them to better access resources and market opportunities.
- Implementation of the existing regulations for a sustainable charcoal sector needs to takefuel briquette into consideration.Fuel briquetting enterprise should be recognized as a productive sector and incorporated in policies such as those on bioenergy,gender, environment and natural resource management.

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10. APPENDICES

Appendix 1.ANOVA Tables

Table 10.1 ANOVA for ash content in table 5.2

Source of variation d.f. * s.s.** m.s.***v.r.****F pr.*****

Treatment	8	26434.63	3304.33	222.24	<.001
Residual	351	5218.84	14.87		
Total	359	31653.47			

*degree of freedom, **sum of squares, ***mean square, variance ratio, *****probability

Table 10.2 ANOVA for calorific value in table 5.2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	3450.531	431.316	370.54	<.001
Residual	351	408.576	1.164		
Total	359	3859.107			

Table 10.3 ANOVA for volatile matter in table 5.2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	155684.04	19460.50	442.79	<.001
Residual	351	15426.39	43.95		
Total	359	171110.43			

Table 10.4 ANOVA for Na in table 5.3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	377634313.	47204289.	7.49	<.001
Residual	27	170060971.	6298554.		

Total	35	547695284.			

Table 10.5 ANOVA for P in table 5.3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	283790.	35474.	5.96	<.001
Residual	27	160705.	5952.		
Total	35	444495.			

Table 10.6 ANOVA for K in table 5.3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	630489554.	78811194.	23.80	<.001
Residual	27	89407029.	3311371.		
Total	35	719896583.			

Table 10.7 ANOVA for Fe in table 5.3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	2.746E+09	3.433E+08	17.22	<.001
Residual	27	5.383E+08	1.994E+07		

Total	35	3.285E+09			

Table 10.8 ANOVA for Al in table 5.3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	2.494E+09	3.118E+08	36.19	<.001
Residual	27	2.326E+08	8.615E+06		
Total	35	2.727E+09			

Table 10.9 ANOVA for Ca in table 5.3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	7.076E+09	8.845E+08	29.16	<.001
Residual	27	8.191E+08	3.034E+07		
Total	35	7.895E+09			

Table 10.10 ANOVA for Cr in table 5.3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	23041.25	2880.16	30.86	<.001
Residual	27	2519.75	93.32		

Total	35	25561.01

Table 10.11 ANOVA for Hg in table 5.3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	173.514	21.689	10.89	<.001
Residual	27	53.771	1.992		
Total	35	227.286			

Table 10.12ANOVA for Pb in table 5.3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	4155.23	519.40	5.34	<.001
Residual	27	2625.00	97.22		
Total	35	6780.23			

Table 10.13 ANOVA for ash content for fuel briquettes in table 6.3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	567.624	189.208	85.96	<.001
Residual	156	343.389	2.201		

Total	159	911.013

Table 10.14ANOVA for ash content for charcoals in table 6.3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	2	4.3120	2.1560	3.14	0.047
Residual	117	80.3835	0.6870		
Total	119	84.6955			

Table 10.15ANOVA for calorific value for fuel briquettes in table 6.3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	529.20	176.40	14.65	<.001
Residual	156	1879.03	12.05		
Total	159	2408.23			

Table 10.16 ANOVA for calorific value for fuel briquettes and charcoals in table 6.3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	6	1184.40	197.40	17.88	<.001
Residual	273	3013.59	11.04		

Total	279	4197.99

Table 10.17 ANOVA for ash contentfor fuel briquettes and charcoals in table 6.3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	6	957.124	159.521	102.77	<.001
Residual	273	423.772	1.552		
Total	279	1380.896			

Table 10.18 ANOVA for volatile matter for fuel briquettes and charcoals in table 6.3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	6	873.324	145.554	15.14	<.001
Residual	273	2624.731	9.614		
Total	279	3498.055			

Table 10.19ANOVA for calorific value for fuel briquettes in table 6.4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	2	83.77	41.89	3.70	0.028
Residual	117	1325.09	11.33		

Total	119	1408.86

Table 10.20 ANOVA for ash content for fuel briquettes in table 6.4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	2	54.594	27.297	23.24	<.001
Residual	117	137.398	1.174		
Total	119	191.992			

Table 10.21ANOVA for volatile matter for fuel briquettes in table 6.4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	2	1162.004	581.002	67.52	<.001
Residual	117	1006.778	8.605		
Total	119	2168.781			

Table 10.22ANOVA for calorific value for sawdust fuel briquettes in table 6.5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	912.87	182.57	13.05	<.001
Residual	120	1678.86	13.99		

Total	125	2591.73

Table 10.23 ANOVA for ash content for sawdust fuel briquettes in table 6.5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	71.2567	14.2513	14.37	<.001
Residual	120	119.0187	0.9918		
Total	125	190.2753			

Table 10.24 ANOVA for volatile matter for sawdust fuel briquettes in table 6.5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	20037.51	4007.50	243.28	<.001
Residual	120	1976.77	16.47		
Total	125	22014.28			

Table 10.25ANOVA for CO for fuel briquettes in Figure 6.2a

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	1810.5	603.5	4.17	0.007
Residual	134	19395.6	144.7		

Total	137	21206.1			

Table 10.26ANOVA for CO for charcoals in Figure 6.2a

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	1	1005.8	1005.8	2.32	0.134
Residual	46	19911.3	432.9		
Total	47	20917.1			

Table 10.27ANOVA for CO for fuel briquettes in Figure 6.2b

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	2	220.3	110.2	0.64	0.531
Residual	87	15032.3	172.8		
Total	89	15252.6			

Table 10.28ANOVA for CO for raw sawdust fuel briquettes in Figure 6.2c

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	2	352.9	176.5	0.68	0.516
Residual	30	7836.1	261.2		

Total	32	8189.1			

Table 10.29ANOVA for CO for carbonized sawdust fuel briquettes in Figure 6.2c

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	2	41.5	20.7	0.20	0.823
Residual	93	9881.8	106.3		
Total	95	9923.3			

Table 10.30ANOVA for $PM_{2.5}$ for fuel briquettes CD+Paper1A, CD+SoilA, CD+CowdungA and CD+GAA and charcoals in table 6.7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	1.531666	0.306333	65.82	<.001
Residual	180	0.837693	0.004654		
Total	185	2.369359			

Table 10.31ANOVA for $PM_{2.5}$ for fuel briquettes CD+Paper1A, CD+Paper2 and CD+Paper3 in table 6.8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	2	0.68436	0.34218	29.00	<.001
Residual	87	1.02665	0.01180		

Total	89	1.71101			

Table 10.32ANOVA for $PM_{2.5}$ for sawdust fuel briquettes in table 6.9

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	549.44	183.15	12.40	<.001
Residual	74	1093.28	14.77		
Total	77	1642.71			

Table 10.33ANOVA for CO_2 for fuel briquettes in Figure 6.3a

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	122149.	40716.	25.21	<.001
Residual	138	222876.	1615.		
Total	141	345025.			

Table 10.34ANOVA for CO_2 for charcoals in Figure 6.3a

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	1	232.	232.	0.04	0.844
Residual	48	283228.	5901.		
Total	49	283460.			

Table 10.35ANOVA for CO_2 for fuel briquettes in Figure 6.3b

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	2	24831.	12415.	7.91	<.001
Residual	90	141311.	1570.		
Total	92	166141.			

Table 10.36ANOVA for CO_2 for raw sawdust fuel briquettes in Figure 6.3c

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	2	1792.	896.	0.53	0.594
Residual	33	55926.	1695.		
Total	35	57718.			

Table 10.37ANOVA for CO_2 for carbonized sawdust fuel briquettes in Figure 6.3c

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	2	3991.	1995.	0.86	0.424
Residual	96	221562.	2308.		
Total	98	225553.			

Appendices 2. Questionnaire used for the household survey in Kibera

URBAN BIOENERGY SURVEY in KIBERA

Enumerator:_______________ **Date:**__ __ / 10 / 2010

A01

Section A : Background Information

A02 Respondent(Name): ____________________ **Telephone** ________________________	Are you household head? **A03[__ __]** 01.Yes *02.No **[No]** → Who is the HHH in Relation to you? **A04[__ __]** 01 Husband 02 Wife 03 Relative 04 Other **88** N/A

No.	**Relation to HHH**	**Sex**	**Age**	**Highest level of Education**
	00. HHH 01. Wife 02. Husband 03. Son 04. Daughter 05. Grandchild 06. relative 07. Orphan 08. No relation	01.Male 02.Female		01. No formal schooling 02. Nursery school Pre-unit baby class 03. Primary 04. Unfinished secondary 05. Secondary completed 06. Vocational Training 07. Pre-college/university courses/unfinished university 08. College/university completed 09. Under school age 10. Other (specify)_________
N0	**A05**	**A06**	**A07**	**A08**
01	[0 0]	[___]	[__ __]	[__ __]✍______________
02	[__ __]	[___]	[__ __]	[__ __]✍______________
03	[__ __]	[___]	[__ __]	[__ __]✍______________
04	[__ __]	[___]	[__ __]	[__ __]✍______________
05	[__ __]	[___]	[__ __]	[__ __]✍______________
06	[__ __]	[___]	[__ __]	[__ __]✍______________
07	[__ __]	[___]	[__ __]	[__ __]✍______________
08	[__ __]	[___]	[__ __]	[__ __]✍______________
09	[__ __]	[___]	[__ __]	[__ __]✍______________
10	[__ __]	[___]	[__ __]	[__ __]✍______________

	SOURCE OF INCOME	**Yearly** (Ksh) 00 N/A
A09	**Agriculture** (Crop & Livestock)	[__________]
A10	**Regular, salaried employment** ex) teacher, doctor, lawyer, researcher etc	[__________]
A11	**Regular paid employment, no benefits** ex) domestic help, watchman etc	[__________]
A12	**Medium size enterprise with employees, premises** ex) factory, workshop, shop	[__________]
A13	**Informal business(mainly family labor)** ex) kiosk, crafts, doing small repairs,transport	[__________]
A14	**Casual laboring** ex) finding work day to day	[__________]
A15	**Relatives/friends outside HH** (including remittances and payments by separated/divorced father)	[__________]
A16	Other: ______________	[__________]
A17	**Total**	[__________]

***Note**

Write down the Calculation

SectionB : What is the source of fuel for LIGHTING?

	Use ? 01 Yes 02 No	**Quantity &Cost**								**Device** 00 No Device 01 Pressure Kerosene lamp 02 Glass Kerosene Lamp 03 Gas Glass Lamp 04 Improved Jiko/ Stove (Kenya Ceramic Jiko) 05 Metal Jiko 06 Three Stone Jiko/ Stove 07 Gas Cooker 08 Energy saving Bulbs 09 Ordinary energy Bulb 10 Kerosene Stove 11 Tin Lump 12 Rechargeable Lamp 13 Other	**Where Do you buy?** 01 Small Scale trader 02 Producer 03 Petro station 04 Communal human biogas plant 05 From old vehicle owners 06 Other	**Distance to Buying Place**	**Utility or Availability or Price Change Etc…**	
		DRY Season				**WET Season**								
		Unit specify /weight Ex) 300mL Bottle 900g block/ball	**Price per Unit** (Ksh)	Weekly Use		Unit (specify)	Price per Unti (Ksh)	Weekly Use						
				Quantity **00 Do not know the quantity**	Cost			Quantity	Cost				Advantage	Dis-advantage
No	**B01**	**B02**	**B03**	**B04**	**B05**	**B06**	**B07**	**B08**	**B09**	**B10**	**B11**	**B12**	**B13**	**B14**
01. Briquette **Producer**										[__ __]	[__ __]	[__ __]		
02 Briquette **Non Producer**										[__ __]	[__ __]	[__ __]		
03. Charcoal										[__ __]	[__ __]	[__ __]		
04. Kerosene										[__ __]	[__ __]	[__ __]		
05. Firewood										[__ __]	[__ __]	[__ __]		
06. Bottled Gas (propane)										[__ __]	[__ __]	[__ __]		
07. Electricity										[__ __]	[__ __]	[__ __]		
08. Biogas										[__ __]	[__ __]	[__ __]		
09. Car Battery										[__ __]	[__ __]	[__ __]		
10. Candle										[__ __]	[__ __]	[__ __]		
11. Solar										[__ __]	[__ __]	[__ __]		
12. Generator										[__ __]	[__ __]	[__ __]		
13. Other										[__ __]	[__ __]	[__ __]		

SectionC : What is the source of fuel for Cooking?

	Use ? 01 Yes 02 No	**Quantity &Cost**								**Device** 00 No Device 01Pressure Kerosene lamp 02 Glass Kerosene Lamp 03 Gas Glass Lamp 04 Improved Jiko/ Stove (Kenya Ceramic Jiko) 05 Metal Jiko 06 Three Stone Jiko/ Stove 07 Gas Cooker 08 Energy saving Bulbs 09 Ordinary energy Bulb 10 Kerosene Stove 11 Tin Lump 12 Rechargeable Lamp 13 Other	**Where Do you buy?** 01 Small Scale trader 02 Producer 03 Petro station 04 Communal human biogas plant 05 From old vehicle owners 06 Other	**Distance to Buying Place**	**Utility** or **Availability** or **Price Change** **Etc…**	
		DRY Season				**WET Season**								
		Unit specify /weight Ex) 300mL Bottle 900g block/ball	**Price per Unit** (Ksh)	Weekly Use		Unit (specify)	Price per Unti (Ksh)	Weekly Use						
				Quantity **01 Do not know the quantity**	Cost			Quantity	Cost				Advantage	Dis-advantage
No	**C01**	**C02**	**C03**	**C04**	**C05**	**C06**	**C07**	**C08**	**C09**	**C10**	**C11**	**C12**	**C13**	**C14**
01. Briquette **Producer**										[__ __]	[__ __]	[__ __]		
02 Briquette **Non Producer**										[__ __]	[__ __]	[__ __]		
03. Charcoal										[__ __]	[__ __]	[__ __]		
04. Kerosene										[__ __]	[__ __]	[__ __]		
05. Firewood										[__ __]	[__ __]	[__ __]		
06. Bottled Gas (propane)										[__ __]	[__ __]	[__ __]		
07. Electricity										[__ __]	[__ __]	[__ __]		
08. Biogas										[__ __]	[__ __]	[__ __]		
09. Car Battery										[__ __]	[__ __]	[__ __]		
10. Candle										[__ __]	[__ __]	[__ __]		
11. Solar										[__ __]	[__ __]	[__ __]		
12. Generator										[__ __]	[__ __]	[__ __]		
13. Other										[__ __]	[__ __]	[__ __]		

Briquette User

Is your household involved in briquette making? **D1[__ __]**01.Yes 02.No

[Yes] → Who is involved? **D2[__ __]**
01 Myself 02 Husband 03 Wife 04 Son 05 Daughter 06 Relative **88** N/A
What are you/he/she making for? **D3[__ __]**
01 Own use only 02 Selling only 03 Both**88** N/A
If you sell, who are your customers in order of priority?
1st**D04[__ __]**2nd**D05[__ __]**3rd**D06[__ __]**
01 Household 02 Food Kiosk 03 Others________
How much do you sell Briquettes?D07[_______]Ksh / 1block

[No] → Why is the important reason to use Briquette? **D08[__ __]**specify✍_______________
01 Price 02 Energy 03 Burning-Time 04 Availability 05 Other **88** N/A

**What is the biggest difference of Briquette from Charcoal?D09[__ __] ***All specify✍_________________
01 Price 02 Energy 03 Burning-time 03Availability 04 Smoke
05 Smell 06 Spark 07 Ash 08 Other

No		**Which is ···**	**Charcoal Briquette ＝？ N/A** **[01] [02] [03] [04] [88]**	(※ Notes)
D10	**Price**	**Cheaper?**	**[__ __]**	
D11	**Energy**	**Stronger?**	**[__ __]**	
D12	**Burning-Time**	**Longer?**	**[__ __]**	
D13	**Availability**	**Nearer?**	**[__ __]**	
D14	**Smoke**	**Less?**	**[__ __]**	
D15	**Smell**	**Less?**	**[__ __]**	
D16	**Spark**	**Less?**	**[__ __]**	
D17	**Ash**	**Less?**	**[__ __]**	
D18	**Other**specify✍__________		**[__ __]**	

What type of food do you prefer to use briquettes? D19[__ __]
01 That cooks for long 02 That cooks for short time 03 Both

Do you use briquette while mixed with other type of fuel?D20[__ __]specify✍_______________01 Yes 02 No
How much are you willing to pay? D21[__ __ __] Ksh / 1 block

Non Briquette User

Do you know Briquette? D22[__ __]
01.Yes   02.No

[Yes]→Why don’t you use Briquette?   D23[__ __]   04 specify✍ ________________
01 Price   02 Energy   03 Access   04 don’t know the value   05 Other   **88**N/A

How much are you willing to pay? D24[__ __ __] Ksh / 1 block
***Note: Explain benefits of Briquette

Is your household involved in briquette making? [__ __]01.Yes 02.No

[Yes] → Who is involved? [__ __]
01 Myself 02 Husband 03 Wife 04 Son 05 Daughter 06 Relative **88** N/A
What are you/he/she making for? [__ __]
01 Own use only 02 Selling only 03 Both**88** N/A
If you sell, who are your customers in order of priority?
01 Households **[__ __]**02 Food Kiosk **[__ __]** 03 Others_________ **[__ __]**
How much do you sell Briquettes?[_______]Ksh / 1block

[No] → Why is the important reason to use Briquette? [__ __]specify✍______________
01 Price 02 Energy 03 Burning-Time 04 Availability 05 Other **88** N/A

What is the biggest difference of Briquette from Charcoal?[__ __] *All specify✍________________
01 Price 02 Energy 03 Burning-time 03Availability 04 Smoke
05 Smell 06 Spark 07 Ash 08 Other

No		**Which is …**	**Charcoal Briquette ＝？ N/A** **[01] [02] [03] [04] [88]**	(※ Notes)
01	**Price**	**Cheaper?**	**[__ __]**	
02	**Energy**	**Stronger?**	**[__ __]**	
03	**Burning-Time**	**Longer?**	**[__ __]**	
	Availability	**Nearer?**	**[__ __]**	
	Smoke	**Less?**	**[__ __]**	
	Smell	**Less?**	**[__ __]**	
	Spark	**Less?**	**[__ __]**	
	Ash	**Less?**	**[__ __]**	
	Otherspecify✍_________		**[__ __]**	

What type of food do you prefer to use briquettes? [__ __]
01 That cooks for long 02 That cooks for short time 03 Both

Do you use briquette while mixed with other type of fuel?[__ __]specify✍______________01 Yes 02 No

How much are you willing to pay? [__ __ __] Ksh / 1 block