SMALLHOLDERS' SOCIO-ECONOMIC CHARACTERISTICS AND THE BIOMASS COOKING ENERGY UTILISATION-FOOD PRODUCTION-GREENHOUSE GAS EMISSIONS NEXUS: CASE STUDY OF WESTERN KENYA

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented for a degree or any other award in any university.

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Recommendation

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DEDICATION

This thesis is dedicated to my parents Stephen and Evelyne Mwaura who taught me to cherish hardwork, honesty and diligence. Also to my wife (Lucy), sons (Stephen and Michael) and daughter (Grace) who encouraged me to keep on working on the document.

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ABSTRACT

With increased population pressure and threats presented by climate change, queries are being raised on the smallholders' capability to achieve food security, engage in fuel energy production and contribute in greenhouse gas mitigation through tree planting. The general objective of this study is to elicit the nexus between biomass cooking energy demand and utilisation, food production and greenhouse gas emissions, with the latter being associated with climate change. Specific objectives for the study are enumerated through each of the academic papers presented from chapter three to six. The papers share a general methodology in data collection with apprpropriate analytical method adopted to respond to each of the specific objective. The thesis is organized into seven chapters with Chapter One addressing the introduction where the background, statement of the problem, general and specific objectives, and the research questions are enumerated. Chapters Two presents a detailed literature review on the study topics including an overview on households' energy demands and choice determinants, energy demands by cottage industries, households' greenhouses emission studies and staple food self-sufficiency among smallholders. A theoretical and a conceptual framework for the study are also presented. Chapter Three presents the study general methodology including description of study area, data sources, sampling designs research and tools adpted and data management. Also presented are the results of the socio-economic characterisation of the smallholders, description of the agricultural food production, and cooking energy production and consumption. Chapter Four details both descriptive and analytical results of determinants of cooking energy choice. In Chapter Five, a paper on the effects of biomass use and demand and agricultural food production among smallholders is presented where synergies and trade-off between cooking energy and food production in resources allocation including labour, capital and land are evaluated. Chapter Six presents a paper on the methodology of estimating smallholders' greenhouse gas emissions, upon which levels and determinants of emissions among smallholders is evaluated. Chapter seven provides a paper assessing the relationship between cooking energy, food production and greenhouse gas upon which conclusions and recommendation are provided. This study has shown smallholding farming system as not only involved in subsistence food production and income generation, but as a complex ecological management systems addressing households' needs including food, income, cooking energy and recreation provisions, and ecological functions including of carbon dioxide sequestration, conservations nutrient cycling systems, improving water systems and soil resource.

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ACRONYMS AND ABBREVIATIONS

ADB	African Development Bank
AE	Adult Equivalent
AFOLU	Agriculture, Forestry and Other Land Use
AGO	Automotive Gas Oil
AHMs	Agricultural Household Models
ANOVA	Analysis of Variance
CLD	Causal Loop Diagram
CO_2e	Carbon dioxide equivalent
DEC	Dietary Energy Consumed
EES	Economic Ecosystem Systems
FAO	Food and Agriculture Organisation
FAOSTAT	Food and Agriculture Organisation Corporate Statistical Database
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GoK	Government of Kenya
ICF	International Classification of Functioning, Disability and Health
IFAD	International Fund for Agricultural Development
IIA	Irrelevant of Independence Alternative
IPCC	Intergovernmental Panel on Climate Change
KES	Kenya shillings
KIHBS	Kenya integrated household budget survey
KIPPRA	Kenya Institute for Public Policy Research and Analysis
KNBS	Kenya National Bureau of Statistics
LA-AIDS	Linear Approximate Almost Ideal Demand system
LCA	Life Cycle Assessment
LEAP	Long-range Energy Alternative Program
LPG	Liquefied petroleum gas
MNL	Multinomial Logit
MNP	Multinomial Probit
MSP	Motor Spirit Premium
OECD	Organisation for Economic Co-operation and Development
SDG	Sustainable Development Goals
SSR	self-sufficiency ratio

TLU	Tropical Livestock Unit
UNEP	United Nations Environment Programme
UNPD	United Nation Development Programme
WHO	World Health Organisation

CHAPTER ONE
INTRODUCTION

1.1. Background Information

The Kenya national development blueprint, "Vision 2030", has identified agriculture as the critical engine of transforming the country into a middle-income economy that will provide a high quality of life to all its citizens in a clean and secure environment (GoK, 2008). Agriculture is expected to contribute towards the country's development through supporting an annual economic growth rate of 10%, reducing the proportion of people living below the absolute poverty level to less than 25%, lowering food insecurity by 30, generating an additional Ksh 80 billion per year, and responding to sustainable development goals as set by the community of nations (GoK, 2009). However, the role of agriculture in achieving these aims is facing new threats presented by rapidly growing energy and water demands, climate change, environmental degradation and biodiversity loss (Hoff, 2011). These are complex risks since they are multi-dimensional, widespread, intractable and far-reaching in effects, hence necessitating inclusive mitigation interventions (OECD, 2011). Moreover, the relationship between agriculture and each of the threats need ascertaining since agriculture can drive climatic change, biodiversity loss, and water and energy demand crisis (World Bank, 2009).

To achieve good results, the new threats should be addressed simultaneously with traditional constraints. The latter include depletion of soil fertility; an ageing rural workforce; poor access to high-yielding inputs; poor rural infrastructure; poor agricultural production financing and credit access; shrinking households' land units; crops and livestock diseases; low adoption of high-yielding technologies (including soil fertility replenishment, germplasm, and agronomic practices); disease and pest infestations; low labour productivity; post-harvest losses and low producer farm-gate prices; high input prices; and challenges associated with poor access to extension services and to recommended agricultural technologies. Other constraints include ineffective policy implementation; insufficient human and financial resources to address agricultural development; poor governance and corruption; poorly developed and ineffective cooperatives; and occasional negative effects of external policies on local agricultural production (GoK, 2008).

Both agricultural and energy development are important drivers of economic growth (Raeeni et al., 2019; UNEP, 2006) and major contributers to anthropogenic greenhouse gas emissions the some cause of climate change (Lynch et al., 2021: Xi-Liu & Qing-Xian, 2018). Developments in one complement the other, for example, electricity and fossil fuels are critical in the production of agricultural inputs (e.g. fertilisers and chemicals). The same energy sources are used in the production of agricultural implements and energizing agro-processing activities, and transportation of both agro-inputs and produce. Fossil fuels are major sources of energy used in powering farm machinery and implements including irrigation pumps and tractors. Bio-fuel production has become an important agricultural activity in mitigating the energy crisis (FAO, 2010). Bio-fuel production by smallholders has raised concerns among development agents as it competes for resources with the conventional agricultural production of foodstuff and fibre thereby undermining household welfare and social harmony (UNEP, 2009). Moreover, increased allocation of land to biofuel production in many countries has been associated with escalating global food shortages and prices, which results in a reduction in accessibility and affordability of basic food (FAO, 2013). Furthermore, farmers' decisions to respond to local and global energy demand crisis by engaging in bio-fuel or woodlot farming in Kenya and how such a choice would impact food insecurity is yet to be documented.

1.2 The Statement of the Problem

Although there has been evidence of households' biomass energy demand and production affecting food production among subsistence smallholder farmers, elicitation of the relationship between these two major production and consumption households' engagement, and how each of the sector will respond when households indulges in greenhouse gas emissions mitigation in Kenya is missing. Moreover, understanding the relationship between household energy sourcing and utilisation, and food production are necessary for comprehensively addressing policy interventions for these critical economic activities either simultaneous or separately particulary now that the menace of climate change is obvious with each of the stakeholder requested to mitigate on their greenhouse gas emissions.

1.3 General objective

The general objective of this study is to evaluate the interlinkages between households' socio-economic characteristics and the biomass cooking energy-food production-greenhouse gas emissions nexus in the smallholding farming system.

1.3.1 Specific objectives

i. To characterise the socio-economic, agricultural food production and cooking energy sourcing and utilisation for sub-counties in western Kenya
ii. To determine factors that influence the choice of cooking energy sources among households in western Kenya;
iii. To evaluate the trade-off of households' biomass energy utilisation and farming on food production among households in western Kenya;
iv. To determine the factors influencing the levels of greenhouse gas emissions among households in western Kenya; and

1.4 Research questions

This study will attempt to provide answers to the following research questions.

i. What are the prevailing socio-economic, agricultural food production and cooking energy sourcing and consumption characteristic of smallholders in sub-counties in western Kenya?
ii. What are the determinants of rural households' choices of cooking energy sources among households in western Kenya?
iii. What are the effects of the trade-off of households' biomass energy utilisation and farming on food production among households in western Kenya?
iv. What are the factors influencing the levels of greenhouse gas emissions among the households' in western Kenya.

1.5 Justification of the study

Insufficient information regarding the effects of households' energy utilisation and production on food and fibre husbandry has hindered the development of robust policies to address food security and agricultural development. Moreover, failure to establish biomass energy demand has hampered the development of an appropriate biomass production strategy in an environment where the production of biomass energy is becoming an integral agricultural activity. Furthermore, even with increasing pressure to expand agricultural production to meet rising demands in food, fibre and biofuel, agricultural potential is fast deteriorating. Threats to agricultural production and potential are attributable to among other factors climate change which has resulted from the escalation in greenhouse gas emissions. Increased levels of domestic and farm greenhouse gas emission have arisen from expanded energy utilisation and agricultural production (Camargo et al., 2013). Information dearth on households' energy choice and levels of utilisation limit the ability of the country to sufficiently account for the overall domestic production. The Kenyan government, through the Last Mile Electricity Connectivity programme, is engaged in intense electricity distribution to the rural area as a means of spurring rural economic development. However, how agriculture will be impacted by the rural electrification intervention remains unknown. Moreover, energy is seen as an axle on which all the sustainable development goals are hinged (UNDP, 2015).

This study will inculcate new theoretical thinking of separating essential meal types in addressing energy choice and relating it to agricultural production. It brings new ideas of addressing agricultural production from a comprehensive approach that introduces new variables that provide crucial insights on sustainable rural development.

1.6 Scope, limitations and assumption of the study

The study area will be Bungoma and Vihiga Counties in western Kenya with its scope covering smallholder farmers. The study will adopt interviewing respondents' where they are expected to recall their investment, consumption and other farming and energy use operations. The sampling procedure assumes that through key informant interviews (counties and sub-counties officers dealing in energy and agriculture), the study will be able to get more information that will allow a robust sampling of locations, wards, and sub-counties to be selected. The timing of the study will be assumed to be normal and representative of what always goes on among farming households in the targeted area. The study pursues to include all variables that may explain the desired outcome, however in some instances selected variables may not necessarily mean that all variables were captured and all those selected variables have the causative effect on the subject of interest.

CHAPTER TWO
LITERATURE REVIEW

2.1 Overview of household energy demand related studies

A major aspiration of Kenya's energy policy (GoK, 2014) is the transition from the use of traditional to modern energy (Mugo & Githua, 2010; van der Horst & Hovorka, 2008). However, the policy assumes a macro approach to energy development and fails to integrate the sector's aspirations with other sectors' development agenda (agriculture included) and socio-economic characteristics of the population that influence the decision to adopt a particular energy source. The policy articulates issues of various energy sources including electricity, fossil fuels (petroleum and coal) and solar, as well as biomass developmental challenges and opportunities. Key challenges for biomass energy development include insufficient information and technology gaps on strategies of engaging other sectors, and how to address competing interests in various land uses.

In a study using a normative economic approach, Githaiga and Mburu (2010) highlighted the interactions between Kakamega Forest and the local community. Governance regimes are important in influencing community access to ecosystem services offered by the forest including firewood collection, mushrooms and fruits gathering, and pasture for livestock. Poor management of the forest leading to its destruction has impacted negatively on the local community resulting in hampered agricultural production and severe disruption of biomass energy sourcing. Difficulties in accessing biomass energy from the forest have influenced local community members to adopt tree planting to ensure supply is restored.

Kituyi et al. (2001) surveyed 2202 households and 117 institutions across various agro-ecological zones in Kenya intending to determine consumption rates for all common biofuels used by households and firms and the factors influencing the observed use patterns. The major biofuel used were firewood, charcoal and crops residues. Per capita utilisation of various biofuels was influenced by agro-ecological zones; meal type, number per day and cooking duration; cost and source distance; stove type; family sizes; ambient temperature; population density; and the general socio-economic characteristics. Sources of biofuel included collection from off-farm, on-farm residues and purchasing. Despite reporting on how households tree (mangoes, cashew nuts, etc.) were used as biofuel, the effect of the destruction of the crops for energy was not appraised.

Wamukoya (1995) surveyed a hundred households to establish the form and quantity of fuel, and the types of stoves used in rural households within Nyeri, Embu, and Kisumu. The study reported households to simultaneous use charcoal, firewood, and residue as a source of cooking energy. The amount of agricultural residue used was influenced by both seasonality of production and type of meal. In all the locations, the budget allocation to fuel accounted for up to 35% of the annual households' income. Access to biomass fuel influenced the amount of each of the energy sources utilised. Agricultural residue used by households as fuel includes maize cob and stalk, sugarcane stalk, and millet and cassava waste. Low adoption of energy-saving stoves was recorded in all locations. Although the study highlighted women and children spending time on biomass collection, quantification and costing of the biomass gathering activity was not done.

Githiomi et al. (2012) reported outcomes of a survey aimed at developing a micro-level wood energy plan that would act as a case study for future decentralized wood energy plans in Kenya was reported. Primary data was collected from the various users including households, cottage industries actors, and service institutions (schools, hospitals, prisons) in the former Central Province to analyze the supply and demand of biomass energy. High proportions of biomass energy deficit estimated at between 42 to 50%were recorded. Simulation of biomass energy supply/demand for a decade using the principles of long-range energy alternative program (LEAP) showed the aggravated deficit in all the locations. Allocation of gazetted plantation forest to fuelwood production, increase of improved stove technology, increase of on-farm tree land area and use of alternative energy sources were the suggested strategies to curb the deficit.

The use of interviews and focus group discussion to investigate how rural households cope with firewood scarcity in dryland areas were adopted for a study in Eastern Uganda (Egeru, 2014). The study by Egeru reported the increased distance and time of firewood collection to have raised annual energy sourcing costs by the estimated opportunity cost of US$ 232 and 580 for those who collected on a weekly and daily basis, respectively. Other strategies adopted include: deliberately planting trees on their farms, use of less preferred low-quality firewood sources, cooking meals once a day, avoidance of cooking some food types, and modifications of biomass stoves. Ejigu (2008)argued that smallholders' participation in bioenergy production provides an opportunity for economic, social and environmental benefits through meeting household energy demand, increasing income, reducing poverty and mitigating environmental degradation.

A comprehensive and ambitious survey was undertaken by KIPPRA (2012) to analyse energy patterns in Kenya. The study had 11 objectives with one of them being to evaluate the energy demand and supply patterns for households, commercial and industrial sectors, transport and institutions by energy type. The survey interviewed 6343 respondents including

3665 households, 1663 enterprises consumers and 857 energy providers. Despite its comprehensive and its strength in economic theory, the study conceptualization severely affected the outcome with the author admitting weakness in data collection and recommending an improved research framework. Failure to differentiate households' cooking and lighting energy had detrimental effects on the results. Some of the study's highlights included a 77%use of firewood in rural Kenya; firewood energy accounted for an eighth (12%) of the energy budget and was the highest. The study indicated households stacking two energy types to account for 54% of the total, while those using a single source accounted for two percent.

In an effort to avoid shortfalls associated with the use of consumption expenditure as a measure of households' welfare, KNBS& SID (2013a) and KNBS &SID (2013b) adopted the use of other socio-economic indicators including energy fuel for cooking and lighting as a welfare measuring asset index. The analysis was based on the 2009 Kenya housing and population census while the 2006 Kenya integrated household budget survey (KIHBS) was incorporated with the census to estimate poverty and inequality measures from the national to the ward level. Dependence on firewood, charcoal, and paraffin for cooking accounted for 90.3, 7.1 and 1.4%respectively of all the households in the country. The utilisation of various energy sources including electricity, LPG, paraffin, biogas, firewood, charcoal, solar and others were highlighted for the counties, sub-counties and wards levels. For example, in Vihiga county dependence on firewood for cooking was by 90.2% of households, with the value at the sub-counties ranging between 85.7% and 95.2%. In Bunyore South Ward, the dependency on firewood for cooking was the highest at 97.5% of the household. The study used an accounting method that assumed households to only depend on a single energy source.

Wambua (2012) analyzed the energy use by the households living within 5km from the edge of the Kakamega forest and its linkages to conservation. The study showed higher dependence on biomass energy sources including firewood and charcoal. Among all the income quantile categorised as ultra-poor, poor, non-poor and well-off, every household was using firewood. Preference of other cleaner energy sources included charcoal, paraffin and LPG were related to the various income categories. Evidence of energy stacking and its penetration was associated with household income. Firewood purchase, collection from the forest and dependency on own trees was by 35, 38 and 47 % respectively. The sourcing of biomass energy was associated with educational achievement, access to forest resource-use permits and the size of land owned by a household. The amount of biomass energy used was associated with sourcing, energy type and household characteristics. Although the study was able to relate household biomass energy sourcing with tree planting, it was limited in highlighting the relationship between agriculture and energy sourcing.

A study to review agroforestry's contribution to food security (Kiptot et al., 2014) highlighted energy and non-energy uses of various trees grown by smallholders. The non-energy uses of trees grown by farmers included sources of food, livestock fodder, fertilisers, boundary hedge and other environmental services. Whichever way the tree products and services were utilised, they were observed to enhance food security through the direct provision and to indirectly increases food (milk, fruits, etc.), productivity and income. Gender dimensions were highlighted as a major factor influencing the benefits derived from agroforestry trees.

A review of existing literature and data was carried out (Ogbonna et al., 2013) to discuss the inter-relationship between energy security and food security in Africa, the potentials of bioenergy production, and the possible negative and positive effects of bioenergy production on food security. The study concluded that bioenergy production would create demand for and stabilize the prices for crops, and increase farmers' income. Regulation of the amount of land to be allocated for bioenergy production was recommended to minimize possible negative effects on food security. The study's assumption of unlimited land and labour resources may not apply across the continent.

An agricultural household model was adopted (Guta, 2015) to explore the effects of fuelwood scarcity on rural livelihoods through an examination of household decisions regarding the allocation of family labour and expenditures on food and energy using panel data. The study showed that fuelwood scarcity or a decrease in the shadow wage of fuelwood collection labour was negatively associated with the allocation of labour to agriculture, and per capita energy and food expenditures. Greater shadow wages for agricultural activities had negative relationships with the allocation of labour to fuelwood collection. Fuelwood scarcity was positively associated with labour allocation to fuelwood collection. This study (Guta, 2015) concluded that fuelwood scarcity has negative effects on household welfare.

2.2 Cooking energy choice determinants' studies

Linear Approximate Almost Ideal Demand System (LA-AIDS) on countrywide household survey data was applied (Ngui et al., 2011) to estimate the income and price elasticities of household demand for different kinds of fuels. Fuel budget share of motor spirit premium (MSP), automotive gas oil (AGO), lubricants, fuelwood, kerosene, charcoal, liquefied petroleum gas (LPG) and electricity was regressed against own and cross prices, regional dummies, income and other households variables (including household size, age, marital status, the highest level of education reached, household head's main economic activity and occupation). MSP, AGO, and lubricants were price elastic while fuelwood, kerosene, charcoal, LPG and electricity were price inelastic. The use of a bundle as a measure of firewood presented a major consistency challenge hence the observed differences in the price of firewood ranging from a Kenyan shilling (KES 1) to KES 15,000 per bundle. Other observations which weakened the study in guiding policy include how energy amount was calculated, and a large number of variables dropped in the regression analysis.

The adoption of the multinomial logit model to estimate socio-economic characteristics that affect shifts from one energy choice to another including firewood, charcoal, kerosene, LPG, and electricity has attracted a couple of researchers. Despite studies being done in different places includingOuagadougou, Burkina Faso (Ouedraogo, 2006), Kisumu (Pundo & Frasher, 2006), Nakuru (Kamau, 2014) andKibera, Nairobi (Yonemitsu et al., 2015) preference and probability of energy choice have been affected by the household head, household, and community socio-economic characteristics. While these studies have provided insights on the shift from the base category to another energy choice type, they have failed to capture the stalking behaviour in energy use. Analytical methods that will incorporate both the energy utilisation levels and the probability of choice need to be applied to sufficiently guide policy on energy planning in the country.

A review of literature for developing countries to argue the importance of adopting dynamic approaches on abundance and scarcity of woodfuel in explaining biomass utilisation at the household level was carried out (Dewees, 1989). Kenya's biomass energy supply and demand were used to illustrate the weakness of analyses of the woodfuel gap in addressing challenges of household energy demands. The study recommended a more dynamic approach to domestic cooking energy concerns as households' characteristics regarding labour and land availability, culture, religions and gender composition among other characteristics does influence how households respond to biomass availability.

2.3 Cottage industries associated energy demand

The agri-processing sector mostly tea and tobacco have been reported to compete for the domestic utilisationof biomass energy sources (Sheya & Mushi, 2000; UN Environment, 2017). Biomass energy sources used by the agro-processing industries were estimated to account for about a fifth of the total utilised in the country (Githiomi & Oduor, 2012). This study on strategies for sustainable wood production in Kenya continued to argue that where tea factories are located, they are the major users of biomass energy sources. The factories use wood-fired steam boilers to generate heat to reduce costs in tea production. On the other side, one of the critical cultural tea management practices is the pruning of the crop to enhance productivity and efficiency in plucking (Hull, 2000). A practice repeated every two years with farmers allocating portions of the crop for pruning to ensure synchronized harvesting and crop management, consequently ensuring farmers have prunings every year. A biomass energy source that has been reported (Mukuna, 2015) to take precedence in use before other sourcing is sought in tea growing areas of rural Kenya, even in locations that could be considered as biomass energy sources endowed. It would be important to understand how local industrial demand of biomass energy against an enhanced household supply of agricultural waste will impact household energy production and consumption behaviours.

A survey to assess socio-economic, environmental and forest resources impacts of tobacco growing in Urambo, Tanzania (Mangora, 2012) reported severe detrimental outcomes of tobacco farming on forest resources as a result of land clearance and high demand of wood for curing. Curing processes requiring woody biomass include construction of the curing barn, tying of the leaves and the actual curing. Fuelwood demand of $23m^3$ was required by every farmer annually for the actual flue-curing of 1400kg of tobacco harvested from a 1.3 Ha. Smallholders in Zimbabwe preferred the biomass energy sources despite efforts by the tobacco industry to provide farmers with coal for curing tobacco (Manyanhaire & Kurangwa, 2014). Using scenario building based on the statistical information for 2009/10 available with the Tobacco Industry Marketing Board (TIMB), the study (Manyanhaire and Kurangwa, 2014) estimated an increase of more than 200 % of woodfuel with an increase of about 20 % of the number of smallholders. This study postulated a requirement of 14kg woodfuel for every kg of flue-cured tobacco leaves, a value it considered inefficiency in relation to the levels achieved in Kenya and Malawi.

Cottage industries utilizing high levels of biomass include brick baking, fish smoking and restaurant (UN Environment, 2017). Magembe et al. (2015) sampled five groups in seven wards to establish woodfuel utilisation for brickmaking in Morogoro Municipality. All brick makers used fuelwood in baking bricks and had a preference for specific species of trees, especially the indigenous ones. On average each of the sampled groups used about $8610m^3$of fuelwood per annum on brick making. In Sudan, brick making was observed to compete with domestic uses for biomass energy including round wood, branches and dung (Alam, 2006) with high levels of deforestation and emissions associated with the cottage industry.With cottage industries accounting for three and 17% of total firewood and charcoal respectivelyof total energy(Githiomi & Oduor, 2012), and the high biomass energy deficit in Kenya (KFS, 2009) it would be important to assess if brick making affects local energy demand. Moreover, the need for evaluating the effects of brick making energy utilisation on households' agricultural activities has been recommended especially in areas the former has replaced the latter as the key livelihood engagement (Abdalla, 2012).

2.4 Household greenhouse gas emission studies

The potential impact of various agricultural programmes on food availability and greenhouse gas (GHG) emissions of 884 households across different agro-ecologies and farming systems in Rwanda were assessed (Paul et al.,2018). Household-level calculations were used to assess the contribution of current crops, livestock and off-farm activities to food availability and GHG emissions. It was observed that livestock and off-farm income were the most important pathways to higher food availability while baseline greenhouses gas emissions were low, ranging between 395 and 1506 kg CO_2 hh^{-1} yr^{-1} per site. Livestock-related emissions from enteric fermentation and manure were the most significant contributors to total emissions across sites and food availability groups. About half of the total greenhouse gas emitted was by 22 % of the households with the highest food availability scores.

Adopting the Intergovernmental Panel on Climate Change (IPCC) scientific methods and guidelines Seebauer (2014) quantified GHG emissions and removals in smallholder conditions using farm data from Western Kenya. The emission profiles of four farm clusters representing the baseline conditions in the year 2009 are compared with 2011 where farmers adopted sustainable land management practices. The results were able to demonstrate the variation in both the magnitude of the estimated GHG emissions per ha between different smallholder farm typologies and the emissions calculated by applying two different accounting tools. About uncertainty related to activity data, the assessment confirms the high variability within various farm types as well as between different parameters surveyed to quantify GHG emissions within smallholder farms comprehensively.

Using a Life Cycle Assessment (LCA) technique and IPCC indices (Okoko et al., 2017) calculated and compared the carbon footprint of five different biomass energy value chains including firewood, charcoal, biogas, jatropha oil, and crop residue briquettes. Review and straightforward accounting of available data in the literature on changes in the environment for Moshi and Kitui in Tanzania and Kenya respectively were adopted for the study. Results indicated the unimproved charcoal value chain was having a big carbon footprint. The value chain for jatropha oil appeared to hold the highest potential for carbon footprint reductions, as long as the feedstock is grown in the form of hedges around plots. The feedstock collection stage of the firewood and unimproved charcoal value chains significantly contributes to their carbon footprints.

2.5 Self-sufficiency in staple food production among subsistence farmers

In a report aimed at mobilizing the concrete and concerted actions required to realize the global food agenda, FAO (2017) estimated about an eighth of the global population to be facing food insecurity. The study also highlighted several global trends influencing food security, poverty and the overall sustainability of food and agricultural systems globally. The highlighted trends, that were also considered optimistic on the future of food and agriculture were population growth, urbanization and ageing; global economic growth, investment, trade and food prices; competition for natural resources; climate change; agricultural productivity and innovation; transboundary pests and diseases; conflicts, crises and natural disasters; poverty, inequality and food insecurity; nutrition and health; structural change and employment; migration and agriculture; changing food systems; food losses and waste; governance for food and nutrition security; and the development finance.

Burchi and de Muro (2016) reviewed five approaches that have been used in the analysis of food security and backed another approach that has been sidelined by scientists. The approaches discussed include food availability, income-based, basic need, entitlement and sustainable livelihood. Despite support for the use of a capability approach that has not been sufficiently exploited in addressing food security, the authors recognized food availability as the most influential. They also recommended its strength in the usage where subsistence agriculture is practised in the less developed economies. Interrelationships were observed between various analysis approaches with a wide similarity of some of the data required for the success in the use of various methods. The advanced approach endorsed the incorporation of socio-economic characteristics including health status, education status and cultural/social issues in food choice.

Using comprehensive, spatially explicit data sets and controlling for the biophysical conditions (Minten & Barrett, 2005) studied how enhanced rice productivity affect its prices, real wages for unskilled workers and key welfare indicators in Madagascar. The choice of rice as the appropriate proxy crop for staples was influenced by its higher per capita consumption; it occupies a majority of cultivable land; and its place in the country's culture and politics. Higher levels of food insecurity and seasonal switching between net sales and net purchases were observed to be more prevalent among poorer farming households. The study recommended enhanced agricultural productivity in reducing rural poverty and food insecurity.

An in-depth review of more than seventy documents including journal articles, books and book chapters, government and international institution studies, reports, working papers, and other grey literature sources on food system(s) published between 2000 and 2017 has been undertaken (Béné et al., 2019). The review revealed the confusion on how the current food system crisis is understood and interpreted. Addressing sustainability in food systems are either on how to close i) the yield gap, ii) diet quality / nutrient gap, iii) the distributional dimension gap or iv) negative impact (food-print) gap. Each of the narratives of addressing sustainability entails a different intervention including enhancing production for the yield gap; (micro) nutrient intake and nutritional status for the nutrient gap; economic and social inequalities and inequities for the distributional dimension gap; and reducing negative impacts on the environment and natural resources for all the food system stages (production, distribution, retail, consumption and waste management).

A review of the literature shows definition and assessment criteria for food security have chronological aspects. Food sufficiency has been of concern as far as 1798 when Malthus linked population expansion to food sufficiency (Dyson, 2001). The Malthusian theory postulated the population expansion to depict a geometrical ratio while that of food productions (subsistence) having an arithmetic ratio. In this aspect, the challenge of food security has been on the imbalance of population against food production. Growth in production, processing and preservation technologies, and commerce potent amelioration of food security concerns. However, development agents have incorporated new aspects in food security definitions to ensure comprehensiveness in its pursuits (Burchi & De Muro, 2016).

A Committee on World Food Security (2012) clarified on use of various terminologies associated with food security. A chronology ofthe definition and key literature influencing the refining of the understanding of food security from 1943 were presented. The clarification of terminologies used in the definition of food security was intended to provide consensus on the issue. While all other aspects of food security including nutritional, environmental and preference are important, availability is fundamental in addressing the food concern.

Using the FAO statistical data related to food production and consumption of the entire continent and for the 52 separate nations in it, Luan et al. (2013) analyzed the changes in the self-sufficiency ratio (SSR) from 1961 to 2007. Staple, mostly cereals and starchy roots were used for the food production and consumption balance analysis to illustrate the capacity for countries to sustain their own population food demands. The study showed that the entire continent and countries are increasingly unable to meet food demand as a result of population expansion exceeding abilities for food production. Regional differences were observed on the trends and status of self-sufficiency ratio in food production and consumption with a decrease in SSR reported largely in the northern and southern part of the continent. Despite differences observed between SSR relationships with GDP between countries, the study recommended the need for intervention in addressing food shortages in the entire continent.

Farmers' coping strategies and determination of the food security index, the food self-sufficiency ratio and cassava self-sufficiency at the household level in three villages of Madagascar were investigated (Noromiarilanto et al., 2016). Household consumption surveys, land use mapping, crop field measurements, allometric equations and canopy cover estimations from aerial photographs for cassava yield assessments were adopted as research methods. Results revealed annual cultivated food crops provided the most of people's diet. Cassava was the most important staple and played a key role in food self-sufficiency. Daily calorie intake was insufficient for most households with the most frequent food insecurity coping strategies being a collection of wild food, off-farm activities and a reduction of meals. Also observed are high seasonal variation in food consumption, food security index and the food self-sufficiency ratio. Cassava yields were observed to be far lower than expected, and despite a high climate-induced risk in crop production, an opportunity for improvements of agricultural techniques to enhance food self-sufficiency existed.

In an effort to estimate daily food security status based on dietary energy consumed (DEC) per adult equivalent (AE), identify households' food insecurity coping strategies and examine factors influencing food production and supply (Ngongi & Urassa, 2014) surveyed farmers in two divisions of Kahama District in Tanzania. High levels of food insecurity existed among households in the study areas with total annual income, the amount of maize and paddy produced, household size, the number of plots owned, and the number of cattle owned significantly influenced the surveyed households' food production and supply. Strategies of enhancing food production through productivity and diversification to off-farm income-generating activities were recommended to improve food security.

A study was designed to identify the main input constraints to improving farm production and the impacts of farm production on the well-being of children including their food security, resilience and engagement in school among farmers in Kenya, Uganda and Tanzania (Inder et al., 2017) showed low agricultural productivity. Low agricultural productivity was associated with limited returns on land and labour with even an increase in the number of adults having a little reduction in the incidence of food shortages.

2.6 Theoretical Framework

The theoretical background for this study builds on the agricultural household models (AHM) by Singh et al. (1986). It considers a household as being involved in dual roles as a producer (of agricultural products) and a consumer (of both purchased and own-produced goods). In this case, an agricultural household is involved in both profit and utility maximization considering the existing constraints. Decisions on what to produce and consume are simultaneously made to maximise profit and utility, considering the limitations presented by resource availability. As long as perfect markets for all goods, including labour, exist, the household is indifferent between consuming own-produced and market-purchased goods. By consuming all, or part of its output, which could alternatively be sold at a given market price, the household implicitly purchases goods from itself (Singh et al., 1986). The model has found a lot of use for agricultural production and consumption systems (Louhichi & Paloma, 2014; Singh et al., 1986) similar to those being practised in western Kenya.

Assume utility (U) for household biomass energy consumption goods and services, such as cooked food, heating and lighting (C_e), consumption of other goods (C_o) and Leisure (Cr).

$$U = \psi_e(C_e) + \psi_o(C_o) + \psi_r(C_r) \quad (2.1)$$

The consumption of biomass energy by a household (C_e) is a function of households' agricultural production (Q_{Ag}), household labour availability (H_T), off-farm employment (I_S), household size (H_S), Land availability (L_T), Income (Y_T), Cattle rearing (C_R), Proportion area under trees (forest) stands (L_F), Costs of biomass energy (P_B), Food cooking duration (F_T) and distance to the forest (F_D).

$$C_a = f_{ce}(Q_{Ag}, H_T, I_S, H_S, L_T, Y_T, C_R, L_F, P_B, F_T, F_D) \quad (2.2)$$

Agricultural production depends on labour spent on crop production (L_A), a vector of agricultural inputs including fertiliser, manure and agricultural waste (F_R, M_R, R_R), a vector of households characteristics (X), a vector of resources utilised in accessing biomass (B) and a proxy measure for the amount of biomass utilised (B_T).

$$Q_{Ag} = f_{Ag}(L_A, F_R, M_R, R_R, X, B, B_T). \quad (2.3)$$

Households operations are constrained by labour endowment, presenting a time constraint; and financial endowment as are price takers for crops, inputs and other goods, introducing a liquidity constraint. The household then maximises utility subject to time constraint, liquidity constraint and non-negativity constraints on the choice variables.

AHMs have been used to evaluate households' decisions on energy use (Chen et al., 2006; Guta, 2015) with household-specific shadow price of firewood corresponding to its unobserved shadow cost of collection. Issues of concerns for agricultural production have been incorporated in the energy model through own firewood wood production, use of agricultural waste and dung as fuel and availability of extra labour for firewood collection (Guta, 2015; Mekonnen & Kohlin, 2008). The study incorporates other "hypotheses" explaining household choices of energy sources including energy stacking (KIPPRA, 2012; Sclag & Zuzarte, 2008) and energy ladder (van der Horst & Hovorka, 2008) to the AHMs. To evaluate the energy stacking hypothesis in energy choice among households, the study will establish levels of energy utilisation for various sources. Estimation of energy choice utilisation levels will allow the study to determine agricultural households' greenhouses emissions, a critical link between energy and agriculture effect on the environment (Gulati et al., 2013) and own and cross-sectoral repercussions. The energy utilisation-environment hypotheses in relation to the choice of household energy have been evaluated through the environmental Kuznets curve (Foster & Rowenzweig, 2003) and poverty-environment (Gulati et al., 2013).

2.7 Conceptual framework

The study conceptualizes that the interactions of availability of water, energy sources and land does influence food and biomass energy production at the household as shown in Figure 2.1. External factors including policies, technological changes, developmental status brought about by market forces and infrastructural access, and natural phenomena (climate changes) affect thepotential for the environment to provide energy services (Githaiga & Mburu, 2010). Environmental factors influence the external forces including conservation policies, intervention technologies and innovations, economic growth and the natural phenomenon.

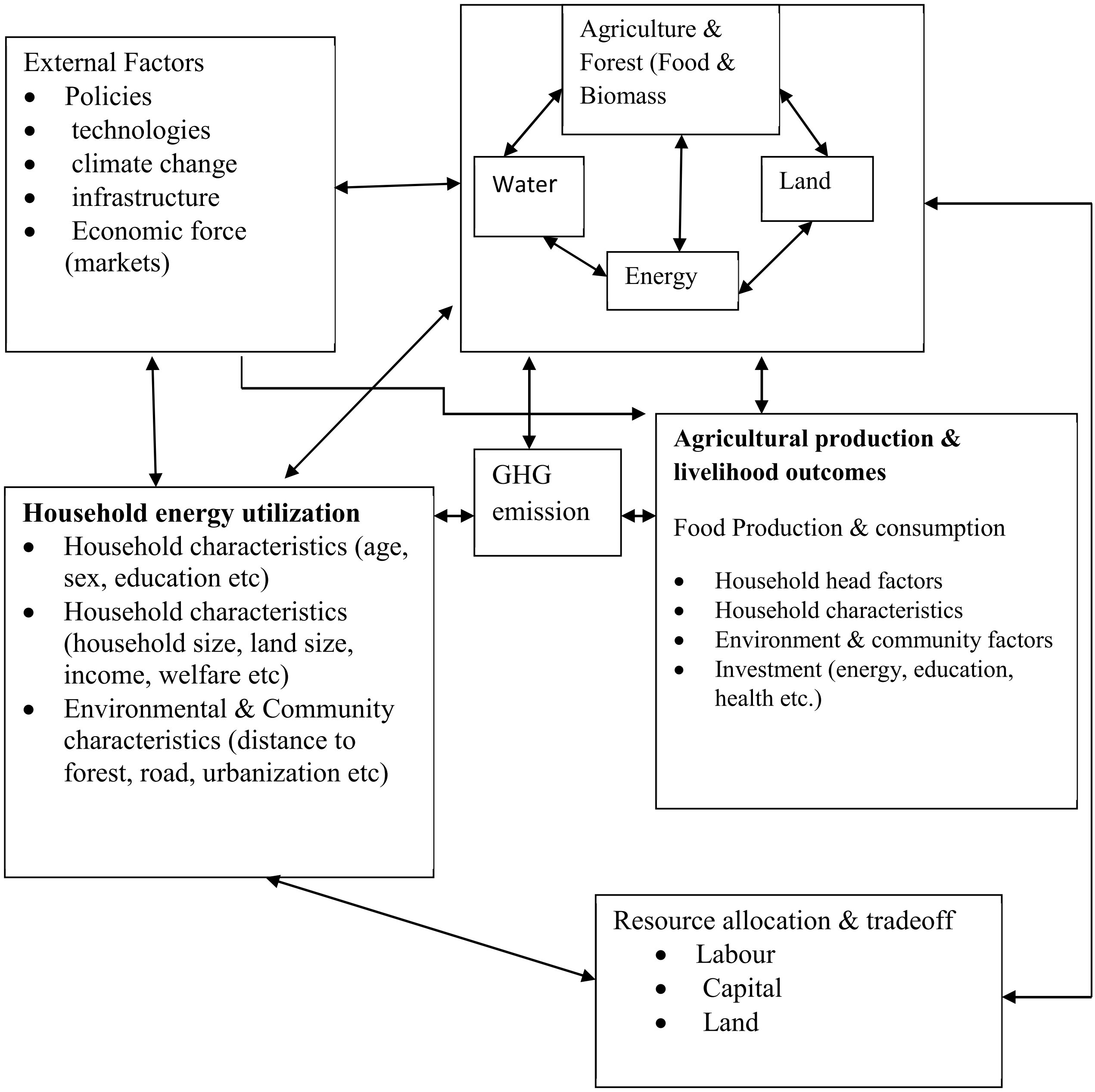

Figure 2.1 Conceptual framework of the effect of the household energy utilisation on agricultural production

Source: Adopted from Guta (2015) and Ringler et al. (2013)

Agricultural households' allocations of factors of production which include labour, capital, landand management are influenced by household characteristics and budget provision for energy. Households' resources allocated or reserved to respond to energy demand include labour for fuel (firewood) collection (Guta, 2015) finances for purchasing LPG, electricity, charcoal and firewood (Kaygusuz, 2011); and land apportioned to forest stands (Chen et al., 2006). Crop wastes and livestock dung which could be used as soil replenishing products is always diverted to cater for fuel (Guta, 2015; Mekonnen & Köhlin, 2008). Decisions to adopt high yielding agricultural technologies are hampered by the desire for ensuring biomass demand if old technology offers fuel (Gesare et al., 2012; Larochelle et al., 2016). The decision for agricultural investment/production is made simultaneously with those of on how energy and other household needs will be met.

Both energy consumption and agricultural production activities by households contribute to greenhouse emissions. The emitted greenhouse gas that contribute to global warming and climate change negatively impacts the agricultural natural base (Gulati et al., 2013) and the agro-ecosystem.The use of biomass as a source of energy deprives the agro-ecosystem of the organic matter necessary as a soil replenishment reserve. A depleted agro-ecosystem will constrict the rate of returns from farmers' investments thereby sustaining low agricultural productivity. Sustained low agricultural productivity leads to impoverished farmers who will be unable to invest in agriculture sufficiently. The farmers will be unable to afford cleaner energy sources thereby having all the welfare indicators (including nutrition, education, health, etc.) impacted negatively (Rosenthal et al., 2018).

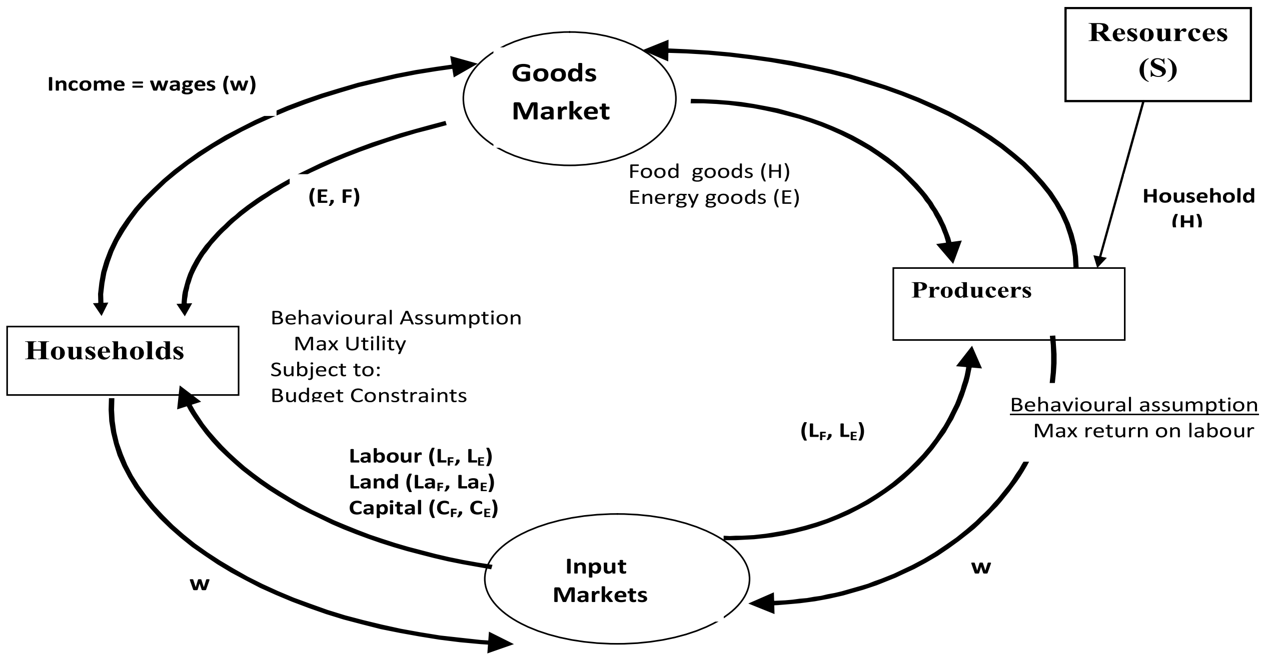

Figure 2.2 A simplified systematic dynamic diagram on household resources' allocation
Source: Adopted from Brander and Taylor (1998).

Figure 2.2 shows the revised Brander and Taylor (1998) model conceptualized to simply the systematic dynamic approach for the study. The model is attractive, because of its simplicity and potential extendibility of the systems approach employed in system dynamics and economics to tackle complex socio-economic-environmental issues. It serves as a good starting point for investigating among other critical factors the substitutability (trade-off), resources allocations, and changing population in evaluating the sustainability and resilience of economic ecosystem systems (EES). The model is also helpful to gain a wholesome picture of the causal loop diagram (CLD) and improve understanding of the complex behaviour of EESs for sustainable development (Uehara, 2012). There is a causal relationship between a household's demands for addressing its utility and what is directly purchased from the market for direct consumption, and investment in resources as inputs of production for food and energy. Inputs for production include land, labour and capital. Households engage in wage sourcing to finance the purchase of goods that meet their utility from the market. These goods may include agricultural (food) and energy products that the household is unable to produce. From this simple diagram, a complex feedback loop with effects either reinforcing (positive) or balancing (negative) will be developed.

CHAPTER THREE

AGRICULTURAL, ENERGY AND SOCIO-ECONOMIC CHARACTERISTICS OF HOUSEHOLD IN WESTERN KENYA

Abstract

Understanding the socio-economic characteristics of smallholders is critical in designing public policy, managerial and extension interventions on agricultural and cooking energy development for smallholders' welfare. In this chapter, we describe the socio-economic, agricultural, food production and cooking energy characteristics prevailing among smallholders, and evaluate the presence of homogeneity among sub-counties on socio-economic, agricultural food production and cooking energy characteristics of smallholders. The chapter also provides the foundation for understanding the factors that will influence cooking energy's effects on agriculture. Despite western Kenya being considered as a homogenous region, some significant differences among sub-counties were observed in socio-economic, households' labour structures, agriculture and cooking energy sourcing characteristics. Across all the sub-counties, a mother in a household allocated more duration to agricultural production (1280 hours) and gathering of cooking energy sources (1280 hours) which accounted for 41 and 68 % of total households' time for respective chores annually. Other sources of labour for households were categorised as that of the father, other members and hired labour. Firewood was the most commonly used cooking energy source accounting for at least 80 % of all households per meal and in all sub-counties. A higher proportion of LPG usage and low levels of firewood utilisation was observed among households with their head in formal employment. Low dependency on firewood for cooking of less than 60 % was reported between September to December of every year, a duration that corresponded to above 20% reliance on agricultural waste. Cooking energy poverty was recorded throughout the year with only less than a tenth reporting sufficiency, however, between April and July, the challenge escalated. Food sufficiency among smallholders in a year exhibited a similar pattern to that of cooking energy.

3.1 Introduction

Knowledge on the socio-economic, agricultural and energy sourcing characteristics of households is insightful on their aspiration, opportunities and challenges in the pursuit of enhancing their welfare. Observed behaviours are a reflection of smallholders' attempts to maximise their utilities as refined by prevailing demands and supply forces, and constraints presented by economic and environmental limitations. Any production or consumption behaviour adopted by the household involves resources allocation. In turn, the behaviour can have positive or negative effects on the household's welfare and resource bases. A household'schoice of cooking energy is critical in that it affects the allocation of productive resources including labour (Das et al., 2019), finances (de Lauretis et al., 2017) and adoption of tree planting on land (Agea et al., 2010). Types and the intensity of resources utilisation on cooking energy compromise what is available for food production. However, cooking energy choice, food production potential and the interaction of the two, food and cooking depends on the smallholders' characteristics.

This chapter provides information on the socio-economic characteristics of smallholders in the sampled sub-counties of western Kenya. The aim of he chapter is to offer a foundation for understanding smallholders' farming practices, socio-economic and environmental characteristics that are critical in influencing agricultural producers' behaviours. Achievements of the formulated four objectives pursued by this thesis are underpinned by an explicit understanding of the smallholder characteristics, and how the analysis was undertaken will depict interactions between the various characteristics and the outcome being tested. Moreover, any intervention recommended including policy, management and technological must be cognizant of the households' socio-economic characteristics for their success.

The research approach adopted postulated a heterogeneous environment in terms of climatic, agro-ecological zones, agricultural production and energy demand and supply as presented by the cluster sub-counties. It is important to affirm the postulated heterogeneity and understand how the differences in the sub-counties affect the socio-economic characteristics. Additionally, these socio-economic differences among clusters affect the hypotheses relationship and may influence the outcomes and the conclusion of the research. Furthermore, the promotion of agricultural and rural development through due consideration of the agro-ecological zones in Kenya (Jaetzold et al., 2007) has been boosted by the devolved system of governance under the new constitution (GoK, 2010). Under the new disposition, agriculture and rural development are domiciled at the county level where planning, interventions' prioritisation, budgeting and resources allocation are undertaken. A more efficient development strategy was postulation under the localization of governance with convergence in policy relevance expected between the county and agro-ecological zones.

It is imperative therefore to provide a critical review on components for agricultural and rural development.While not all the characteristics have been selected as variables to test the research questions, a comprehensive understanding of the smallholder provides deep insight into the farming system and the relationship being tested in each of the other three core-specific objectives. The specific objectives of this chapter were to describe the socio-economic, food production and cooking energy characteristics, to evaluate the presence of differences between sub-counties on socio-economic, food production and cooking energy characteristics of smallholders and to provide the foundation of understanding the effect of cooking energy utilisation and demand on food production.

3.2 Methodology

3.2.1 Description of the study area

The sampled population was in the western region of Kenya comprising Counties of Busia, Bungoma, Kakamega and Vihiga. This area presents a region with the highest agricultural potential in Kenya. Rainfall is high and well distributed throughout the year and ranges between 400 to 2400mm per annum. Rainfall in this area unlike other regions in the country is highly reliable, mostly above 60 %. Due to the region's wide climatic variations from cold to hot temperatures (14ºC - 32ºC), they are optimal for a broad range of agricultural activities. The main agro-ecological zones found in this area include the upper and lower midlands (Vihiga and Kakamega County), Upper Highlands, Lower Highlands, Upper Midlands and Lower Midlands (Bungoma County) and Lower Midlands (prevalent in Busia County). Humidity ranges from high (Mt. Elgon, Bungoma) to moderate along Lake Victoria in Busia. Figure 3.1 shows the geographical location of the sampled cluster sub-counties in western Kenya and their respective Counties.

Western Kenya presented a region of interest for energy demand, consumption and biomass energy production in several ways (Torres-Rojas et al., 2011). First, the region is densely populated, experience low agricultural productivity despite being considered as a region of high potential (Jaetzold et al*.,* 2007), was readily accessible for research and had several studies on agriculture and agroforestry development. Western Kenya had been reported to have the highest biomass energy deficit and challenges of inefficiency in biomass energy utilisation (Carvalho et al., 2019). The sampled area has a rich diversity of agro-climatic zones and had been perceived to have a poorly diversified dietary pattern (Oniang'o et al., 2003) which could impact forms and types of energy consumed. Due to patterns of demographic and socio-economic changes; agricultural and energy demands trends results from studies targeting this region were foreseen to have a wide application in other parts of the country. Though western Kenya offers an important case for understanding energy

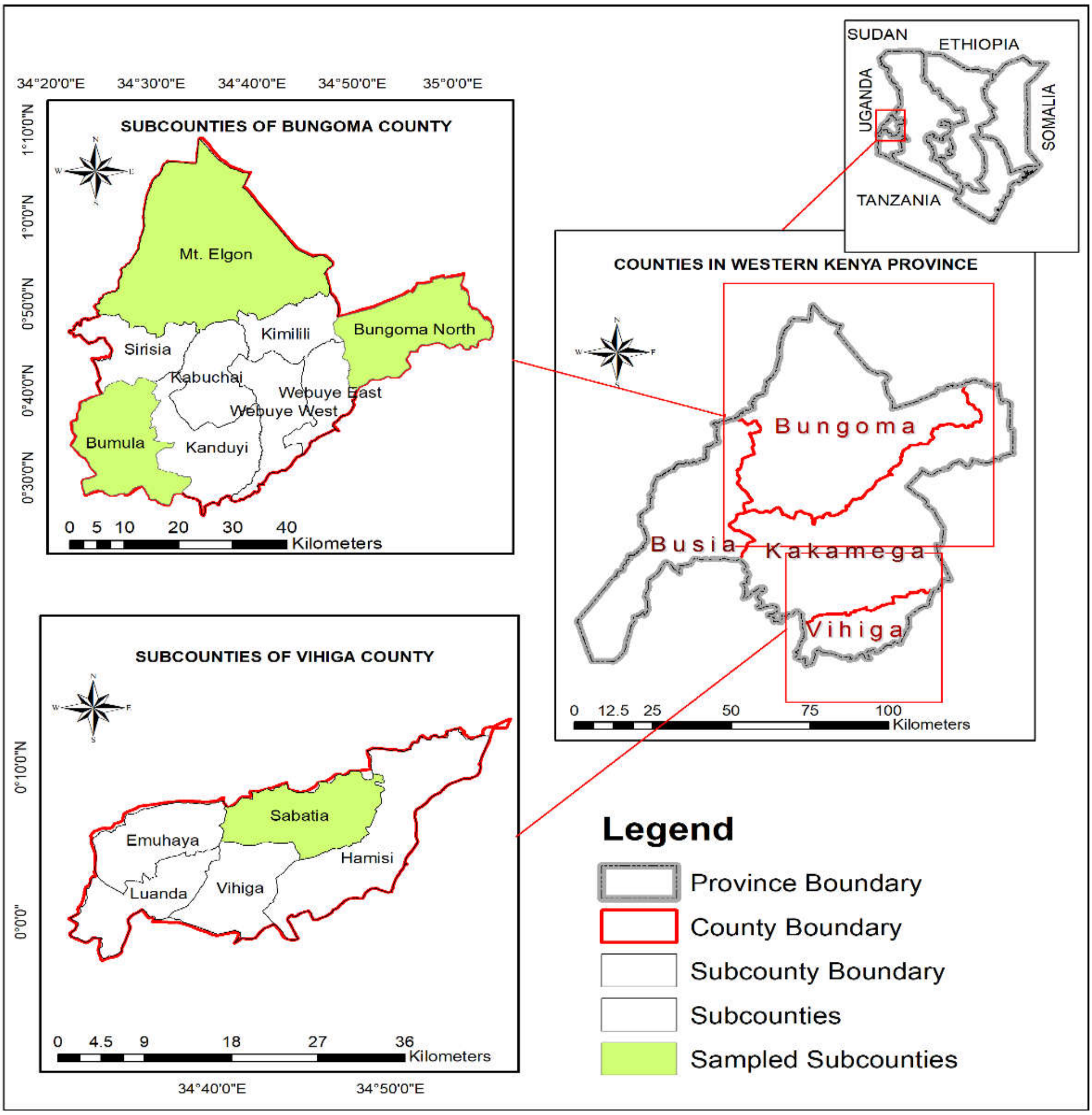

Figure 3.1 Location of the sampled counties and sub-counties in western Kenya

Source: (Esri Eastern Africa, 2017)

utilisation and the development of energy policies, previous studies left research gaps (Barnes et al., 2011; Torres-Rojas et al., 2011).

Four sub-counties clusters with unique agricultural, energy and socio-economics characteristics were purposely selected for the study. Selection of the virtual heterogenous sub-counties clusters was influenced by the socio-economic characteristic including population density, agricultural activities, availability of other known energy using sub-industries including bricks, agri-processing industries specifically tea and tobacco, poverty levels, budgets allocation for rural electrification; access to forests (Commission of Revenue Allocation, 2011) and counties having different agro-climatic regions (Jaetzold et al., 2007). In pursuance with the sub-counties clusters that were sampled through the purposive sampling criteria, the locations fell in the two rural counties of Vihiga and Bungoma. Bungoma is located in coordinates $0^{o}47$'N to $0^{o}89$' N and $33^{o}92$' to $35^{o}095$'E while Vihiga County is $0^{o}036$'S to $0^{o}199$'N and $34^{o}56$' to $34^{o}92$'E. Through the selected purpose sampling procedure the study attempted to get heterogeneous clusters to allow comparison on agricultural production, agricultural–energy nexus production and consumptions, energy consumptions and socio-economic characteristics. Table 3.1 shows agricultural, energy and socio-economic characteristic description of the sub-counties that were sampled for the study.

3.2.2 Data sources

Primary data collection methods were used for the study. Data collected and the methodology adopted availed demographic, economic, general energy, agricultural production information that was used to predict determinants of household cooking energy choices among rural communities, effects of household biomass energy utilisation and demand on food production; and estimate energy and agricultura production related greenhouses gas. A survey was used to collect information from respondents. Other methods to collect primary data that were adopted included key informant interviews. Focus Group Discussion (FGD) was used to gather information on effects, response and feedback and also to fill historical and cross-sectional information gaps that could not be efficiently gathered through interviews of household respondents.

Secondary data available among institutions where informants were consulted were captured to enhance the primary data collected. Information that was gathered through secondary information collection included efforts on the promotion of various energy conservation techniques. Journal, reports and other publications were also reviewed.

Table 3.1 Characterisation of heterogeneous clusters in Western Kenya

Characteristics	Bumula	Bungoma North	Mt. Elgon	Sabatia
Agro-ecological zone	LM3 (lower Midland, Cotton zone)	UM4 (Maize-sunflower zone)	LH1 and UM (Tea–dairy and Cattle sheep zone)	UM1 (Coffee-tea zone)
Altitude (asl)	1200-1400m. asl	1500-1900m asl	1950-3000 m asl	1500-1900 m. asl
Annual mean temperature (°C)	22.4- 21.6°C	21.0 -18.8 °C	18.0 – 7.0 °C	21.0-18.5°C
Mean annual rainfall	1200-1450 mm	1150-1400 mm	1600-1800 mm	1800-2000 mm
[1]Cereal legume growing days	230-270 days	210-230 days	>360 days	365 days
Soil Physiographic characters	clay to cracking clay, in many places abruptly underlying a topsoil of friable sandy loam; in places saline and sodic: dystric PLANOSOLS, dystric and vertical GLEYSOLS and pellic VERTISOLS; partly saline-sodic phases	Well-drained, deep, strong brown to yellowish red and dark red, friable sandy clay loam to sandy clay	Well-drained, deep to extremely deep, dark reddish-brown to dark brown, friable and slightly smeary clay, with an acid humic topsoil; in places shallow and rocky. ando-humic NITISOLS and humic ANDOSOLS	Well drained, very deep, dusky red to dark red and also dark reddish brown to yellowish red, vary friable clay: nito-rhodic FERRALSOLS and ferralo-orthic ACRISOLS

Community and culinary behaviours	Bantu, Bukusu sub-tribes; Native settlement	Bantu, Luyha including Bukusu & Maragori sub-tribes. Scheme settlement.	Largely highland Nilotics, Sabaot. Native with controversial scheme settlement	Bantu, Maragori sub-tribes; Native settlement
Population density	Population 633 persons per km^2 (CRA, 2011)	Population 572 persons per km^2 (CRA, 2011)	Population 180 persons per km^2 (CRA, 2011)	Density 1377 persons per km^2 (GoK, 2013a)
Agricultural activities	Maize-bean intercrop, tobacco, groundnuts, tobacco other horticultural	Largely maize	Maize, vegetables, onions, Irish potatoes, tea being introduced	Maize-bean intercrop, tea
Energy related industries	Tobacco curing & brick baking	Large farms and commercialized maize farming	Wet and cold weather necessitates warming of houses	Wet and cold weather necessitates warming of houses
Biomass information	Competing needs for biomass energy. Tobacco requirement to change the biomass energy dynamism.	High production of maize ensures availability of crop's waste as energy choice option.	Neighbouring a public forest reserve (Mt. Elgon Forest)	A public forest reserve about 15-20 km (Kakamega Forest). Tea farming with pruning supplying biomass energy. A tea factory located in the sub-county.

[1] Indication of session of agricultural production activities

Source: CRA (2011), GoK, (2013a) and Jaetzold et al. (2007)

3.2.3 Sample design

Using the Cochran sample size formula (Cochran, 1977) for determining sample size, the number of agricultural households to be sampled for the interview was established. The formula was selected based on its ability to provide an adequate sample size that can estimate results for the whole population with good precision and its wide utilisation by social scientists (Anderson et al., 2004). The formula was appropriate for the study as western Kenya has a finite and a large number of households (KNBS, 2013) and information gaps on the households attribute in relation to the study objective was generally missing. Despite the stratification of the sampled sub-counties into virtual clusters based on the general ecological, agricultural and socio-economics characteristics, the household population was considered homogenous. In this case, a maximum degree of variability was postulated and hence a 50 % was adopted in determining the sample size. The study results were accepted at a 95% confidence level and an acceptable margin of error of about five percent.

Cochran sample size formula is presented as

$$n_o = \frac{Z^2 pq}{e^2} \quad 4.1$$

where n_o is the sample size being determined. Z is the confidence level, p is the degree of variability, q is equivalent to $1 - p$ and e is the acceptable margin of error. The sample size was evaluated by fitting values into the Cochrane formulae

$$n_o = ((1.96)^2(0.5)(0.5))/(0.05)^2 = 385 \quad 4.2$$

However, to ensure balanced review and analysis of the heterogeneous clusters a hundred (100) households were interrogated per sub-county.

A stratified sampling procedure was adopted to establish the number of samples to allocate to each of the virtual clusters of the sub-counties. The choice of sampling procedure was influenced by the desire to provide greater precision, guard against an "unrepresentative" sample, obtain sufficient sample points to support a separate analysis of any subgroup and the need for an efficient sample (Wright et al., 2007). The equal allocation stratified sampling method (Tekin et al., 2017) was adopted to apportion the sample to every virtual cluster sub-county. Despite the larger coefficient of variations for the estimators associated with equal allocation sampling methods than the others (Neyman and the proportional), its choice was prioritised to enhance the achievement of efficient estimations for strata means (Wright et al., 2007). Moreover, information dearth on the factual characteristic of households beyond the geographical description used for virtual clusters in Table 1 exists.

The adopted sampling method reduced the possibility or risks of a false conclusion as a result of Type 1 and Type 2 errors (Hazra & Gogtay, 2016). Despite a total number of households in the region reported at 841075 households (KNBS, 2013), the proportion of the agricultural households, the target of this study was unknown and their distribution in either the farmlands or the many urban, peri-urban, formal and informal settlements (Greiner & Sakdapolrak, 2013; KNBS, 2012) was unidentified. Furthermore, the cost of resources (time and financial) implication for sampling in different sub-counties was missing to allow the adoption of optimal allocation sampling methods (Wright et al., 2007).

Wards and villages where the research was conducted were sampled purposively using the criteria for stratified sub-counties and a simple random respectively. Wards were postulated to be heterogenous with ecological, agricultural and socio-economics' characteristics differences. Spots of high population density, high altitude, highlighted high-biomass energy areas as influenced by cottage industries (extensive brick baking) and agro-enterprises (tobacco curing and tea processing factories) and other energy associated characteristics, and unique agricultural commercial features among others. Wards were selected after undertaking a reconnaissance survey that involved undertaking a stakeholders' consultation. Simple random sampling was used to specify sub-locations/villages in each ward where farmers were interviewed.

The survey's respondents were selected using a simple random criterion in each of the sub-location sampled. Information on households listing (ICF, 2012) from the counties and national government and the Kenya National Bureau of Statistics (KNBS) to aid in sampling and weighing of data was unsuccessfully sought. The efforts were futile as no such information appeared to be available by the officials consulted for the information. With the absence of the listing by the governments and KNBS, a recommended listing criteria (ICF, 2012) was adopted to select the sub-locations and households for targeting. A reconnaissance survey was undertaken as a familiarization strategy for the targeted area to allow robust sampling of wards and sub-locations to be selected for the study. Upon settling on the sub-location and villages for the survey, researchers covered about half a kilometre from the local shopping centres and sampled every other 5th household perpendicular to the main road.

3.2.4 Survey Instrument

A survey was undertaken to collect information from the sampled households. A Semi-structured questionnaire was administered to the selected respondents. To respond to the research objectives the questionnaire had various modules addressing specific information of interest. The questionnaire had modules querying households on their socio-economic characteristics; cooking energy sourcing and utilisation; agricultural production information; levels of maize production and utilisation; and household's ranking of food staple and cooking energy sufficiency over different months of a year. The survey gathered information at a household level with the targeted respondent being a household head (Appendix A1). A pilot testing of the questionnaires was used to enhance the quality of the research tool. A checklist of key questions was developed upon consultation with county energy and agricultural policy implementers. The checklists developed were used during key informant interviews and focus group discussions (Appendix A2).

3.2.5 Weighing of biomass energy sources

To quantify biomass utilisation and therefore supplement the questionnaire in data collection, firewood, charcoal and agricultural residues were weighed to demonstrate use and collection per day. Biomass "bundle" was quantified by using a weighing balance to determine the real mass of biomass utilised by the sampled households. Estimating the real weight of a bundle has been a major challenge to researchers as it has differed between individual respondents (Wambua, 2012).

The sampled respondents to the survey demonstrated the amount of biomass used or collected per (day/week, etc.) upon which the researcher weighed and recorded the number of different forms of energy used in the questionnaire. With a demonstration of the number of various biomass sources (cow dung, crops wastes, firewood, and charcoal), households were requested to separate quantity that was used and/or collected per meal/day. A unit price for various separated biomass weights was estimated. The amount separated was weighed and recorded in the questionnaire. The respondents were also requested to provide insights on energy sources used for cooking over different periods of the year. Weighing of biomass aimed at aiding in the establishment of real and shadow prices for biomass sources, shadow wages for biomass sources collection, revealed preference for biomass energy sources and the weights were input for the empirical analysis used to determine the study's objectives.

3.2.6 Data analysis

Data collected was analyzed using descriptive and inferential statistics with the assistance of STATA computer software packages. Microsoft Excel programme was used in data processing (entry). The database was later exported to the analytical computer software. The entered data was cleaned and tested for conformity before being analyzed. Data were analysed using economic models that corresponded to specific objectives as postulated before the study.

3.3 Results and Discussion

3.3.1 Smallholders socio-economic characteristics by cluster sub-counties

Table 3.2 shows the outcome for multiple comparisons of means for the socio-economic characteristics associated with various cluster sub-counties. In the analysis, a Bonferroni test was used to counteract the problem of multiple comparisons associated with false positivity on statistical significance. Despite western Kenya having been studied as homogenous in terms of agricultural production and socio-economic aspects, some differences were observed among sub-counties. Households' heads age differences were significant ($p<0.05$) between Sabatia and those in Mt. Elgon and Bumula, and Bungoma North compared to Elgon. The twelve years of differences observed on household head age and the farming experience between the older and the younger smallholders by sub-counties could instigate other variations in characteristics beyond the agro-ecological between the sub-counties. The wide household head's age variations between sub-counties were attributable to land settlement patterns experienced in the regions (Burke & Jayne, 2014; Jayne & Muyanga, 2012; Liu et al., 2019; Nkonya et al., 1998). In these research outputs the small scale landholding and its trends provide insights on demographic characteristics and response of the settlers. In this regard, Sabatia happens to be the old settlement associated with the African reserve, while other areas including Bungoma North were part of the white settlement where land was re-allocated to locals after independence (Wayumba, 2019).

Household head age variable influencing agricultural production has been reported in a number of studies (Beck et al., 2019; Musafiri & Mirzabaev, 2014; Urgessa, 2015), with the observed outcome enhanced or constraints by the adoption rates of high yielding technologies. Energy sourcing and consumption have been associated with the age of the households' heads (Soltani et al., 2019) imply that age differences observed among the sub-counties would magnify cluster variations beyond those arising from the agro-ecological and biomass energy sourcing factors. Moreover, the twelve years differences observed on household head age and the farming experience between the older and the younger smallholders by sub-counties could instigate variations in farming stages (Ahmad et al., 2020; Burke & Jayne, 2014)

Table 3.2 Households' socio-economic characteristics by sampled cluster sub-counties

Household characteristics	Overall	Bumula (B)	Mt. Elgon (E)	Sabatia (S)	Bungoma North (N)	Prob > F	p-values	Sub-County differences.
Household head age(years)	49.8	47.1	44.4	56.2	50.9	*0.000*	*P< 0.05*	*E<B/S/N, E< B/S/N,*
Experience farming (years)	20.8	17.3	17.1	28.8	19.1	*0.000*	*P< 0.01*	*S> B/E/N*
Adult total (> 18 years)	2.8	2.5	2.8	2.7	2.9	*0.0718*	*n/s*	*N/A*
Children (7-18)	1.7	1.8	2.1	1.5	1.5	*0.0227*	*P< 0.05*	*S< E*
Children below 7	1.2	1.7	1.4	0.6	1.0	*0.000*	*P< 0.01*	*S< B/E, B>N*
Household size	5.26	5.6	5.8	4.6	5.1	*0.0001*	*P< 0.01*	*S< B/E*
Adult equivalent	4.34	4.54	4.82	3.9	4.15	*0.0006*	*P < 0.05*	*S> B/S*
Adults proportion (%)	58	48.9	54.8	65	61	*0.0001*	*P < 0.01*	*B<S/N, E< S*
Female proportion (%)	44	41	44.7	49	42	*0.1900*	*n/s*	*N/A*
Fathers average age (years)	47.7	44.5	43	54	49.5	0.000	P<0.05	*E< S/N, B< S*
Mothers average age (years)	44.6	40.4	39.2	52.5	45.4	0.000	P<0.05	*S> B/E/N, E<N*
Household head education (years)	9.48	9.4	9.1	8.7	10.8	*0.0023*	*P< 0.05*	*N> SE*

No significant differences were observed in the proportion of female-headed households among the sub-counties. The gender of a household head has been attributable to household welfare (Horrell & Krishnan, 2007), food security (Silvestri et al*.,* 2015), agricultural productivity (Peterman et al., 2011), labour allocations (Idowu et al., 2013; Palacios-Lopezet al., 2017) access to extension services and adoption of agricultural technologies (Mishra et al., 2015) and energy production and consumption technologies (Rahut et al., 2017).

Overall the average number of individuals was 5.3 per household with Sabatia recording significant (P<0.05) smaller families compared to Mt. Elgon and Bumula sub-counties.The household size observed was consistent with that reported in other studies (Sikei et al., 2008). Household size represents both demands for food and other necessities (Fisher & Lewin, 2013; Zhou et al., 2019) and also in smallholding settings, labour provision (Fink et al., 2018; Sikei et al., 2008). Households with large numbers of individuals require more food and are obliged to invest highly to meet other necessities including education, clothing, housing, energy, and leisure. More individuals in a household represent extra hand for undertaking domestic chores including those associated with agricultural production (Beck et al., 2019; Fink et al., 2018) and energy sourcing (Carter et al., 2018).

The in-depth characterisation of households by adult equivalent, age groups and gender allowed in the separation of household size as being either an asset or a liability (Biran et al., 2004). The characterisation also provided a more precise way of estimating dependency, labour availability and its allocations (Sikei et al., 2008). Members of the households were categorised into adults above 18 years, those between 7 and 18 years, and children below 7. Through this categorization by age, the actual household members available for labour allocation could be estimated. Such grouping was important as they signal trade-offs in responsibilities among household members in different age categories (Beck et al*.,* 2019) associated with shifts in the prices, profitability, and agricultural enterprises. Reallocation of labour from adults to other categories points to change in agricultural enterprises prioritisation. Despite being discouraged in many countries, it is not unusual to find children under 12 years being involved in agricultural production (Kotb et al., 2011) and firewood gathering. Moreover, minors are involved in caring for their younger sibling (Biran et al., 2004).

Across different ages categories heterogeneity were observed among the sub-counties. Sabatia reported significant (P< 0.05) low numbers of children below 7 years at an average of 0.6 individuals per household compared to Bumula and Mt. Elgon. An indication of low labour requirement to cater for the children (Bray & Dawes, 2016) in Sabatia compared to other sub-counties. The number of children below 7 years was significantly lower in Bungoma North compared to those reported in Bumula. The spatial differences observed between agegroups among regions in Kenya and comparison to its immediate neighbouring countries (GoK, 2013b) have been attributed to the total fertility rate. The total fertility rate has been observed to depict an indirect relationship with education years of a community, per capita income, birth control measures and positively correlated with religiosity (Gotmark & Anderson, 2020). However, this study could not elucidate the relationship argued by Gotmark and Anderson (2020) and the differences reported could have been largely associated with the age-structure of the households' characteristics where crude birth rates correlate with the age of the mother and resources endowment (GoK, 2013b). According to the document (GoK, 2013b), at the age brackets 20 to 29 years the highest births of between 200 to 250 children per 1000 women are reported in Kenya.

Household size and age-based categories including total number of household members and those between 7-18 years were slightly higher in Mt. Elgon implying enhanced labour availability compared to other sub-counties.Also enhancing labour access for agricultural production and firewood gathering is the low proportion of formal employment among household heads in Mt. Elgon, which was only significant compared to Bungoma North. The adult equivalent is associated with food and nutritional requirement by age, gender and reproductive responsibilities as a fraction of an estimated adult reference value (2,550kcal), and hence provides an overall household food consumption pattern (Claro et al., 2010). Mt. Elgon with an adult equivalent of 4.82 had a significantly higher number than those reported in Sabatia and Bungoma North implied more food requirement per household in the former compared to the other two. Appendix C1 shows how the adult equivalent was allocated to gender and age.

Efforts to characterise households into various age patterns were targeted for understanding labour resource structure and its respective allocations (Beck et al., 2019; Biran et al*.,* 2004) in agriculture, firewood gathering, and off-farm (Sikei et al., 2008). Households' heads in Sabatia were relatively older with both parents being above 52 years while those of Mt. Elgon were younger by at least 12 years. The age differences between the two clusters could influence labour allocation with older spending less time in both agricultural production and off-farm employment (Sikei et al., 2008).

Every household had about three adults, two adolescents, and a child. The labour resources orientations at the household point at a well-endowed force with dependency for child care being low (Bray & Dawes, 2016) and intra-household agricultural activities allocations (Beck et al., 2019) considered optimal. Although only adults are eligible for labour participation, other household members were involved in various economic and welfare chores, similar to other reported cases (Suda, 2001). Age has been linked to different levels of agricultural activity productivity and efficiencies (Rufai et al., 2018). The relationship between age and productivity depicts an inverted parabolic curve with the most productive age bracket for farmers quoted as between 35 and 44 years (Tauer, 1995). Other factors that have been associated with age in agricultural production include levels of input use (Rufai et al., 2018), family composition (Bedemo et al., 2013), and contentment working in the sector (Guo et al., 2015).

On average households heads in Bungoma North had higher levels of educational achievements (10.8 years), compared to their counterparts in Mt. Elgon and Sabatia. Increased achievement of high formal education by household heads was attributable to enhanced access to formal employment. Formal employment was associated with expanded opportunities of increasing smallholder income (Urgessa, 2015) that boosts capital available for investment in both agriculture and other consumer goods, energy included. Moreover, education levels achieved and formal employment status could also be considered as strong indicators of aspiration for engagement in agricultural production (Verkaart et al., 2018) and the type of energy adopted (Rahut et al., 2019). In smallholding community the formal employed mostly enter agricultural production with some underlying profitability objective unlike the non-formal employed farmers whose participation in this sector is largely limited to survival tactic.

The proportion of adults in a household was an indicator of the levels of dependency, labour availability, and the family's levels of communal cohesiveness (Hilder et al., 2018). All these factors associated with the proportion of adults are critical in influencing labour allotment, household welfare, and production and consumption behaviours. Households in Sabatia had significant ($p<0.01$) more adults (65%) compared to those in Bumula and Mt.Elgon. In regards to family structure, households in Sabatia had a bigger proportion of its members available for labour allotment and its consumption behaviour was expected to be more aligned to agricultural development, unlike in Bumula which needed to avail more of its resources to children care including schooling fees, clothing, and leisure.

Table 3.3 shows results of Chi square analysis comparison for categorical data among sub-counties with a Bonferrori test. Significance differences were observed between Mt. Elgon and either one or more of the other sub-counties. The proportion of households with title deeds for their land, relying on their farm for firewood, and adopting energy-saving cooking

Table 3.3 Chi square for categorical data among clusters sub-counties

Household characteristics (%)	Bumula (B)	Mt. Elgon(E)	Sabatia (S)	Bungoma North(N)	X2	P-values 1	Bonferrori P-values 2	Cluster's differences
Female headed	19	29	24	17	5.5767	0.134	*n/s*	*N/A*
Formal Employment	13	8	11	19	8.594	0.035	*0.0083*	*E<N*
Title deed	63	31	66	62	31.862	0.000	*0.0083*	*E<S/B/N*
Farmer group	32	17	24	27	5.8010	0.122	*n/s*	*N/A*
Solar (%)	58	51	30	68	30.192	0.000	*0.0083*	*S<E/B/N*
Credit access (%)	33	15	20	25	9.0735	0.028	*0.0083*	*E<B*
Reliance farm biomass	73	35	58	69	33.0829	0.000	*0.0083*	*E<S/B/N*
Improved cooking	52	22	40	54	26.5901	0.000	*0.0083*	*E<S/B/N*
Conscious of warming	15	25	31	13	12.9871	0.005	*0.0083*	*N<S*

Note: n/s = not significant; N/A = not applicable

Table 3.4 Comparison socio-economic and energy consumption characteristics of households among cluster sub-counties

Household characteristics	Bumula (B)	Mt. Elgo(E)	Sabatia (S)	Bungoma North (N)	F	Prob > p	Bonferrori P-values	Cluster's differences
A firewood outing duration (minutes)	52.6	110	77.2	71.4	*8.14*	*0.000*	*P < 0.05*	*E>S/B/N*
Firewood fetching HH members (no.)	1.6	1.2	1.3	1.4	*3.69*	*0.0122*	*P < 0.01*	*E< B*
Weekly firewood gathering time (min)	239	389	267	202	*3.33*	*0.0198*	*P < 0.05*	*N< E*
Average firewood distance km)	0.31	1.2	0.44	0.28	*16.3*	*0.000*	*P < 0.01*	*E>S/B/N*
Weekly household expenditure (KES)	2422	1805	1889	1508	*5.95*	*0.0006*	*P < 0.05*	*N< B*
Per capita daily expenditure (KES)	72.4	60.4	74.8	60.4	*2.89*	*0.0352*	*n/s*	*N/A*
Sufficiency in maize production (%)	78	75	65	87	12.4	0.0000	P < 0.01	*S< B, S< N, E< N*
Number of houses in a household	1.9	2.03	1.7	2.2	*7.24*	*0.0001*	*P < 0.05*	*B< N, S< E, S< N*

Note: US$ = KES 100; n/s = not significant; N/A = not applicable stoves were significantly lower in Mt. Elgon in relation to all other sub-counties. Access to a public forest readily improved availability of firewood affecting the observed low dependency on own farm and the incentives to invest in energy-saving technologies.

Table 3.4 shows energy associated socio-economic characteristics in the sampled sub-counties. Households' efforts in accessing firewood could be symbolised by the number of individuals involved in its gathering, the distance covered in accessing the firewood source, and the time spent in its sourcing per outing (Stewart et al., 2010). The highlighted indicators are used in assessing invested efforts for the common access resources (Martins, 2014). All the three indicators for household's efforts represent the shadow prices of the energy sourcing, and also could provide an insight on how the chore is prioritised and traded-off among other consumptive needs and production activities. Households in Bumula involved a relatively higher number (1.6 individuals) of members in firewood collection compared to the other sub-counties, however, the number was only significantly higher than that of Mt. Elgon. The number of individuals involved in firewood sourcing among households has multiple implications on energy access. These implications include households' preference of firewood gathering ahead of other activities; demand for firewood necessitates the allocation of more human resources and sourcing for the firewood not requiring any specialization entailing the entry of any willing household's member.

Other firewood accessing efforts apart from the number of individuals were more associated with Mt. Elgon compared to other sub-counties. On average, an outing of firewood fetching took 110 minutes in Mt. Elgon and about half of that duration (52.3 minutes) in Bumula. The average distance households' members walked to fetch firewood in Mt. Elgon (1.2 km) was incomparable with other clusters. The reported firewood fetching duration per outing and the distance travelled to assess firewood in Mt. Elgon were significantly higher than those recorded for the other sub-counties. The weekly duration for fetching firewood in Mt. Elgon was twice as much of the time households in Bungoma North used for the same activity with the differences being significant ($P<0.05$). On weekly basis, households in Bumula and Sabatia on average took 148 and 123 minutes less on firewood fetching than those in Mt. Elgon. Despite the differences being insignificant, the more than two hours duration was ample time, especially where labour is highly in demand for agricultural production.

Addressing the issues of energy security and self-sufficiency in the production of biomass energy among clusters was complex for a number of reasons. The efforts of firewood fetching as revealed by duration per outing, weekly time taken, the number of individuals involved, and distance covered demonstrated Mt. Elgon as facing challenges of access of firewood. However, because the sampled households in Mt. Elgon rely largely on the forest reserve for firewood, the opportunity cost of its access should be a concern. For most residents of Mt. Elgon, it appeared more rational for them to source their firewood from the forest reserve despite the distressing efforts due to its proximity.

Prioritisation of firewood sourcing from the reserve could have been associated with sufficiency in both quality and species diversity (Agea et al., 2010). Moreover, the availability of household labour and lack of competing allocation options could have driven households to assign more effort to biomass energy sourcing.

The wide differences observed on reliance on own farm for firewood between sub-counties were attributed to specific cluster's biomass energy sourcing characteristics. Significant low dependency on own farm for firewood was observed in Mt. Elgon (35%) compared to other clusters. Households surveyed in Mt. Elgon were near a public forest reserve that allowed access to its resources. Preference of firewood from the forest and its access influenced the levels of dependence on their farm for the biomass source. Households in Sabatia had small landholding compared to those in Bungoma North rendering dependence on their own farm untenable. In Sabatia, the reduced reliance on own farm in firewood sourcing was compensated by its collection from road reserves and purchasing (Murphy et al., 2018). Even those who fetched biomass fuel from their farm largely supplemented it with purchases, especially during harsh weather. The selling of firewood was observed to take place more in Sabatia, where the commodity was available in most shops. Itinerant traders using bicycles and motorcycles were also reported to engage in households' visits to sell firewood across the clusters except in Mt. Elgon and Bumula.

Despite expected high demand attributable to wood fuel competition arising from the extensive brick baking enterprise and tobacco curing in Bumula (Jaetzold et al., 2007), the outcome returned a different insight. Variables used as indicators of wood fuel access constraints including firewood duration per outing of gathering and dependence on own farm for household's firewood sufficiency, showed households in Bumulanot being energy limited in comparison with other sub-counties.The households in the sampled area were no longer heavily involved in tobacco farming and its curing. Moreover, it was observed that not all tobacco farmers were involved in tobacco curing but instead, it was being undertaken by specific individuals as value-added services. Brick baking was rarely undertaken by farmers but by some specialized service providers. Cultivation of a herbaceous crop specifically sunflower and leaving land furrow during the second season enhanced the availability of biomass energy in Bumula and Bungoma North.

Households' weekly expenditure was Kenya shillings (KES) 2422, 1889, 1805, and 1508 in Bumula, Sabatia, Mt. Elgon, and Bungoma North, respectively. Daily per capita expenditure was highest in Sabatia and lowest in Bungoma North with the differences being significant. Despite all the sampled households being in rural settings, Bumula was more commercialized due to the presence of a tobacco processing plant that initiated differences in markets and consumptions behaviours unlike other cluster sub-counties sampled. Despite, the presence of a tea processing factory in Sabatia, its integration with socio-economic aspects of the local community was not as pronounced as those associated with tobacco in Bumula.

Using the income poverty indicator illustrated by weekly household expenditure, smallholders in Bungoma North were the poorest and those in Bumula the less poor. However, these consumption numbers were cautiously interpreted in relation to poverty prevalence (de la O Campos et al., 2018; Ferreira et al., 2015; Jayne & Muyanga, 2012: Odusola et al., 2017) as households were own food producers and the budgetary allocations for consumption catered for supplemental need (FAO, 2014). The caution in consumption expenditure data interpretation for farmers arose from other researchers' concerns on comparison of spending against welfare. A detailed analysis of consumption expenditure for Ghana showed allocation for food and rent accounting for 73% and four percent respectively of daily per capita expenditure (Zereyesus et al., 2017), two significant budget lines that subsistence farmers don't incur as they produce their food and live in owned houses.

The inclusion of maize production sufficiency in meeting food demand provided more insights into rural spending. A comparison of per capita expenditure against food (maize) production sufficiency showed households in Bungoma North reporting the lowest per capita consumption expenditure (KES 45) but achieving the highest maize production sufficiency of 86%. In Sabatia, the highest per capita daily consumption expenditure (KES 65) corresponded to the lowest own maize production sufficiency (55%). Bungoma North reported significant higher own food production sufficiency compared to Mt. Elgon and Sabatia sub-counties. Per capita expenditure for Bungoma North were significantly ($p<0.01$) lower than those of Bumula, while those of Mt. Elgon were only lower to levels reported in Sabatia.

3.3.2 Household labour characteristics

The households by definition represented a family unit that always partook the key meals together. The households were observed to represent mostly nuclear families (Cancian & Reed, 2009) with a mother, a father and children. In some cases, other relatives including either a parent, a sister or a brother to the father or mother were part of the households. In the households, a mother's membership to the family is voluntary through marriage to the ‘father’ and is a female leader of the family with both production and reproduction duties including childbearing rights. On the other hand, a father's membership in the family is voluntary through marriage to the ‘mother’, who is a male leader of the family with both production and reproduction duties including childbearing rights within a household.

Table 3.5 shows the household characteristics associated with labour provision activities and their allocations. On average, households' participation in agricultural production in 2017 was 2417 hours, of which 41% and 26% were accounted by mother and father respectively. Household participation in agricultural production was highest in Mt. Elgon with 2825 hours allocated to the activity. A higher level of mother’s participation in agricultural production labour was in Bumula (44%) and the lowest was in Bungoma North (38%). An hour allocation of labour by a male household head was replicated by an additional 60% by the mother. The agricultural production participation ranking was consistent with the agroecological studies outcomes (Jaetzold et al., 2007) where both sub-counties on higher altitudes (Sabatia and Mt. Elgon) allocated more labour than those on lower zones. Other factors that affected labour requirements in agricultural production included farm size (Bedemo et al., 2013), enterprise labour intensity (Leonardo et al., 2015), mechanisation opportunity (Sims et al., 2016) and crops’ annual production seasons (Fink et al., 2018). Except where rainfall patterns allow for more than one production season, the adoption of supplemental irrigation enhances yield per season and the number of seasons per annum (Mwaura & Muwanika, 2018).

Another domestic chore that a father allocated very little time to is firewood gathering. In all the households, proportionate allocation of labour to firewood gathering indicated the chore to be greatly associated with women as has been reported in other studies (Levison et al., 2018; Sikei et al., 2008). An hour investment of the father on firewood gathering responded to 205, 37, 28, and 25 hours of mother inputs in the same in Bumula, Mt. Elgon, North Bungoma, and Sabatia respectively.

In a household, a mother was observed to significantly participate in all domestic economic and welfare activities including agricultural production, firewood gathering, and

Table 3.5 Socio-economic and households' labour allocation characteristics among clusters in western Kenya

Household annual labour allocation in hours (2017)	Bumula (B)	Mt Elgon (E)	North (N)	Sabatia (S)	F(Prob)	Differences among sub-counties	Sub-counties differences
Father total time	1431.9	1185.7	1519.1	992.9	0.0602	n/s	N/A
Mother total time	1999.6	2502.5	1967.8	1951.5	0.0057	p < 0.05	E>N/S
Other household members total time	1847.8	1924.3	1948.8	1805	0.9807	n/s	N/A
Hired labour total time	82.2	92.0	430.9	52.3	0.0002	p < 0.01	N>B/E/S
Father involvement in farm chores	323	471	371	349.7	0.0870	n/s	N/A
Mother involvement in farm chores	1269	1528	1062	1257.5	0.0003	p < 0.01	E>N
Other household members farm chores	1308.6	1674	1323	1398	0.6399	n/s	N/A
Hired labour farm chores	70.3	84.9	393.8	84.9	0.0001	p < 0.01	N>B/E/S
Total households' agriculture	2900.8	3672.5	2930.9	3005.4	0.0601	n/s	N/A
Father firewood allocations	0.2	4.2	0.8	1.6	0.1976	n/s	N/A
Mothers firewood allocations	151.7	267	108.6	140	0.000	p < 0.01	E>N/S/B
Other members firewood collection	60.6	67.5	62.6	122	0.2625	n/s	N/A
Household total firewood duration	210.6	339	177	259	0.0103	p < 0.01	E>N
Father off-farm allocations	1040	711.4	1154	674	0.0457	n/s	N/A
Mothers off-farm allocations	194	406	576	284	0.0151	p < 0.05	N>B
Household total off-farm duration	1232	1117	1457	958	0.0151	p < 0.05	N>B/E/S

NB: n/s = not significant; N/A = not applicable off-farm employment. With this outcome, where allocation to domestic chores seems to be unbalanced and determinants among household members unexplained, the key question is on the homogeneity of available labour for agricultural household modelling (Rufai et al., 2018). The outcome of this study is consistent with those that have considered women (mothers) to be heavily engaged in all household's productive and reproductive activities (Murphy et al., 2018). In this case, leisure which should account for all other duration not captured in economic chores is mostly associated with the father and the extra adult in every household.

3.3.3 Cooking energy sourcing by meals for various cluster sub-counties

Households were observed to use various options of energy sources for preparing supper. Figure 3.2 shows the proportion of households using various cooking energy sources for supper preparation in the cluster sub-counties of western Kenya. In the sampled area, nine in every ten households considered firewood as an option source of energy for supper preparation. Charcoal and twigs were used in supper preparation by 13% of households in western Kenya. In all the sub-counties, an identical pattern of firewood accounting for more than 80%, charcoal, and twigs averaging 10% was reported as energy sources for supper preparation. The outcome showed that the community in the region highly depended on biomass associated energy sources for cooking.

The overutilisation of biomass energy sources calls for enhanced planting of trees either locally or in other areas which will export energy sources to this region. Already forest resources in agricultural potential areas including western Kenya, where households could revert to gathering firewood or burning charcoal in response to demand for biomass energy sources are largely restricted to protected indigenous and plantation estates that have been reported to be extensively degraded (MoEF, 2019; Ototo & Vlosky, 2018). Farm forestry remains the only viable option to satisfy the demand for biomass energy and the drive for expanding the country's forest cover of at least 10% (Brockerhoff et al., 2017; MoEF, 2019). With the high population density, shrinking agricultural land, food insecurity, and competition for land between food crops and trees, adoption of the latter could be limited. However, while the shift from food production to tree planting provides farmers with the opportunity to engage in a high-value enterprise, the decision may render smallholders entirely dependent on the food market. Trees take longer to mature (Miller et al., 2017) with it earliest sales proceeds expected in about ten years. Households' vulnerability to food security, income proceeds and threats to livelihoods as they await trees to mature, may render them prioritise staple food production ahead of trees farming.

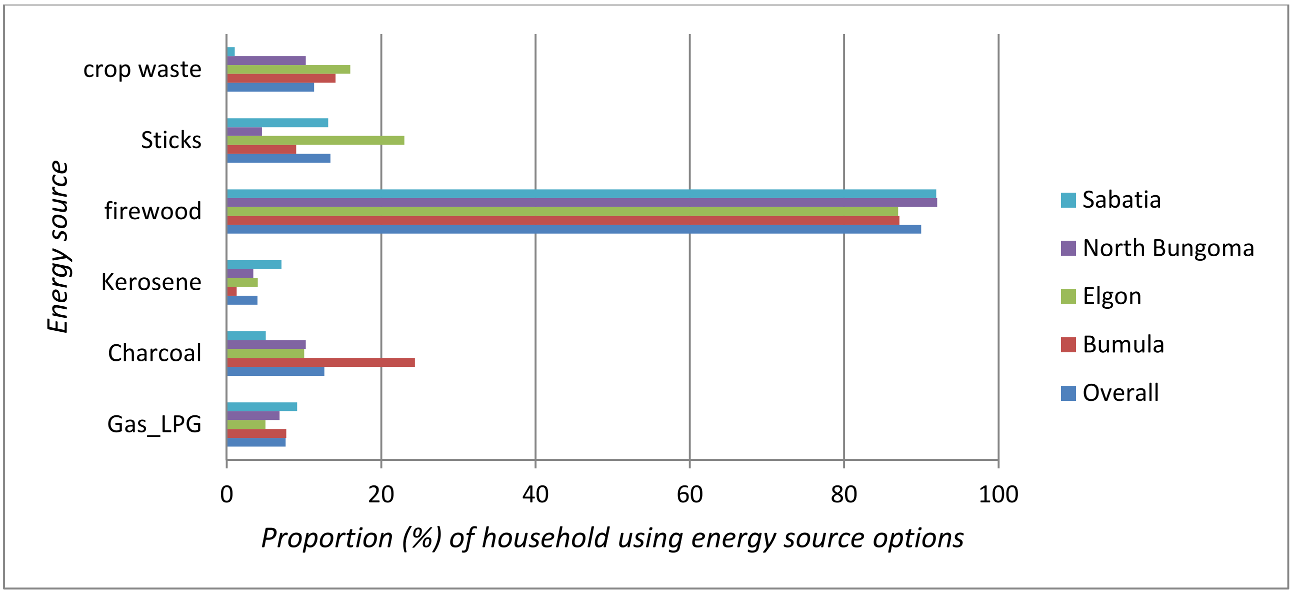

Figure 3. 2 Proportion of households using various cooking energy sources for supper preparation for the cluster sub-counties in western Kenya

Despite trading-off in land area, agroforestry practices that promote both multi-purpose trees and food crops should be promoted. The practice will allow farmers to continue in food production practices while waiting for the trees to mature. Moreover, as the tree grows the farmers would be able to enjoy other services and benefits associated with tree farming. Benefits associated with trees include shade, enhanced soil fertility and soil conservation, livestock foliage, resin, fibre, wood products, food products (fruits, honey, nuts) and financial returns, among other ecosystem services (Miller et al., 2017). However, agroforestry has its limitations, with some form of tree and food crops separation being necessary to avoid competition for nutrients, light and space, and allow ease and efficiency in crop management and operations. Where agroforestry is undertaken, trees are planted in specified patterns including individual trees, windrow, hedges and woodlots (Henry et al., 2009) to maximise land use.

Despite a call for shifting to other sources of energy as viable options (Malla & Timilsina, 2014; Murphy et al., 2018), the observed low usage of agricultural crop waste, LPG, and kerosene that accounted for 11%, 8%, and 4% of households respectively, testifies to high dependency on forest resources. Even with the few differences among the clusters, a comparison of energy sourcing for supper preparation appears to exemplify characteristics associated with particular sub-counties. For example, in Bumula, a slightly less proportion of households (87%) used firewood and more (25%) utilised charcoal for supper preparation. The slight differences in energy choice options between Bumula and other sub-counties for supper were attributed to its urbanite nature. On its part, Sabatia performed poorly on crop's wastes as supper cooking energy source largely due to the constraint in sizes of agricultural land that limits acreage of crops, amount of yield (Jaetzold et al., 2007), and associated by-product for use as fuel.

Figure 3.3 shows the proportion of households using various cooking energy sources for lunch preparation among the clusters. No major differences were observed between the patterns on cooking energy sources used for lunch and supper preparation across the clusters. Firewood was the most relied upon cooking energy source across all the clusters which were reported by more than 80% of households. The proportion of households utilizing charcoal for preparing lunch decreased sharply from those observed for supper in all the clusters except in Sabatia. The rationale for increased preference for charcoal in supper preparation

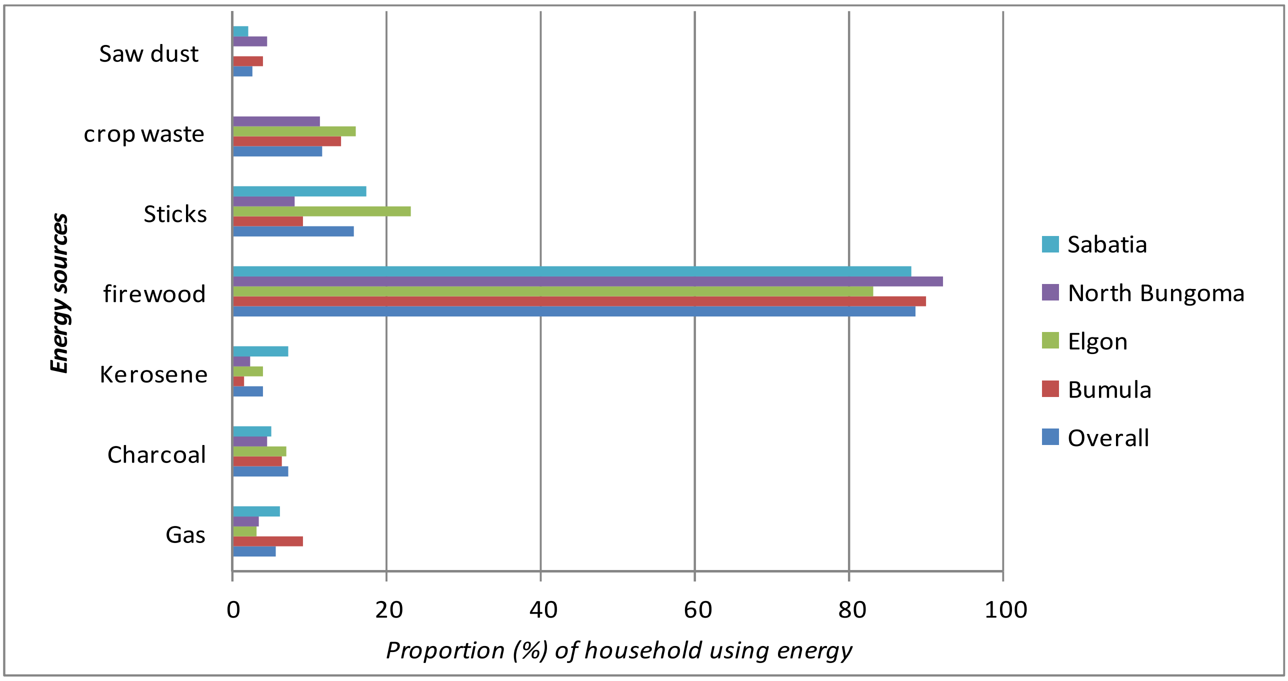

Figure 3.3 Proportion of households using various cooking energy sources in lunch preparation for the cluster sub-counties in western Kenya

than for lunch could not be certainly explained. However, it was suspected that its twin function of warming the house environment and cooking with less smoke compared to firewood made it a preferred choice in supper preparation. In Kenya, as in many other developing countries, outdoor cooking for firewood using households has been reported (Langbein et al., 2017), to reduce exposure to smoke associated with this form of cooking energy. Lunch could have been a better candidate for outdoor cooking as it is done during the daytime compared to supper prepared at night and hence the relatively low usage of charcoal. Despite the small proportion of households using LPG for supper preparation among the clusters, a reduction in those using this cleaner energy source for lunch preparation was reported in Mt. Elgon, Bungoma North, and Sabatia.

Overall, no major differences were observed on the heavy reliance on biomass energy used for preparing lunch and supper on one side and breakfast on the other. Figure 3.4 shows the proportion of households using various cooking energy sources in breakfast preparation for the cluster sub-counties in western Kenya. Similar to other major meals, a large proportion of households rely heavily on firewood, twigs, and crops' wastes in that order for preparing breakfast. The increase in households using LPG for preparing breakfast was observed across the sub-counties compared to other meals. For the entire sampled area, households using LPG for breakfast preparation rose to 13% from nine and six percent for supper and lunch respectively. The use of LPG to prepare breakfast failed to record an increased proportion of households compared to those adopting it for supper only among households in Mt. Elgon. In Bumula, Bungoma North, and Sabatia the proportion of those

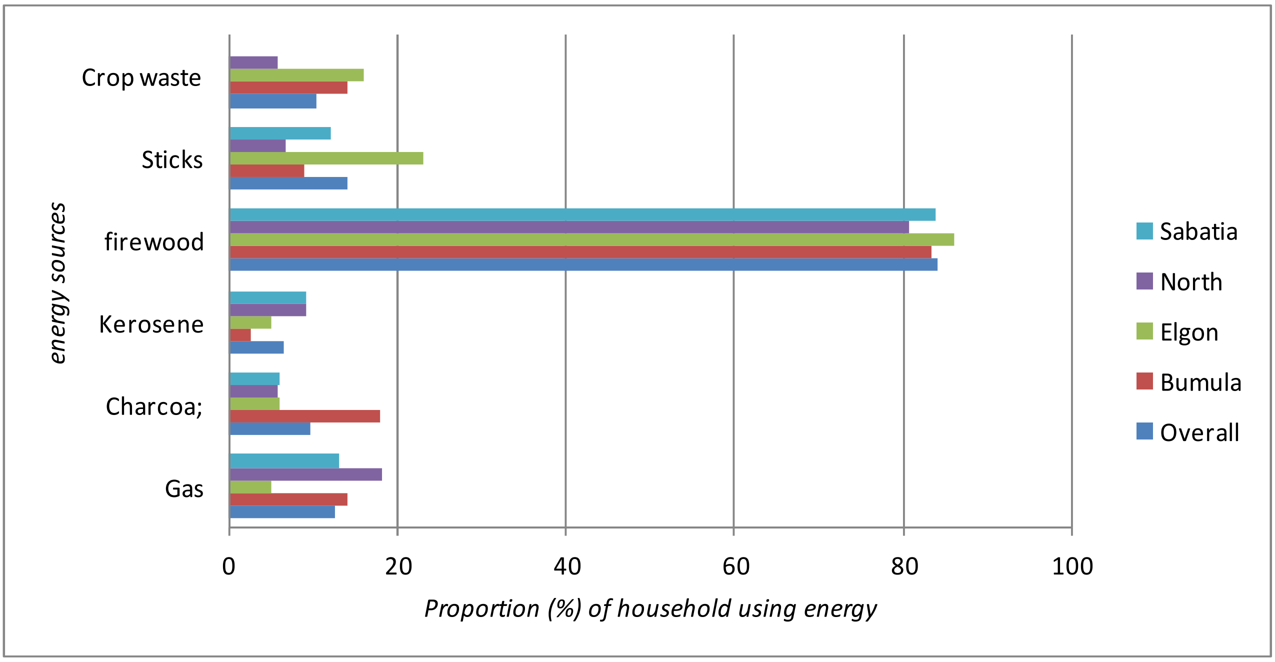

Figure 3.4 Proportion of households using various cooking energy sources for breakfast preparation for the cluster sub-counties in western Kenya

using LPG for breakfast preparation was 14%, 18%, and 13% compared to eight, seven, and nine percent respectively on supper. In Bumula, charcoal as an energy source option for breakfast preparing among households was 18% compared to 24% choosing it for supper. Only six percent considered charcoal an option for breakfast making compared to a tenth for those choosing it for supper preparation in both Mt. Elgon and Bungoma North.

The observed pattern on cooking energy choice by the key meal-type implies that decisions on energy use in households are articulated at different settings and moments. Some of the considerations that the households may wish to make based on the prevailing situation may include saving time during cooking and the form of energy source to adopt for different food types as also reported by other studies (Akinoso & Oladeji, 2017; Destro et al., 2013).

As household members desire to disperse punctually to various daily chores including school, formal employment, and off-farm and farm commitments, the usage of LPG increases as an energy source for breakfast preparation. Setting up of firewood and charcoal stoves takes longer and hence observed reduction in their choice for breakfast preparation. Nevertheless, the initial investment in LPG energy, economic welfare, and accessibility to refilling points may have hindered the increased adoption of this cleaner energy source. The cooking of hard cereals and other food types that require a substantial amount of energy and time to prepare drives households to adopt energy sources perceived to be cheaper including firewood (Nerimi et al., 2017).

3.3.4 Cooking durations for various meals in western Kenya

Figure 3.5 shows durations used by households in different clusters for making the three key meals. In all the sub-counties, preparations for breakfast took the least time among the three major meals made by households. In Mt. Elgon, breakfast preparations took 33 minutes. In Bungoma North and Bumula sub-counties, breakfast preparations took 22 minutes. On average, households in Sabatia took half an hour to prepare breakfast, and twice the time (64 minutes) to prepare lunch. Lunch and supper took almost the same durations to prepare in Sabatia unlike in all the other sub-counties where substantial time differences were reported. Compared to other sub-counties, households in Sabatia used the shortest duration for lunch preparations and the longest for supper cooking. On average, the total duration taken to prepare the three key meals ranged between 159 and 215 minutes. In Bumula, households took the shortest durations to prepare all the key meals while Mt. Elgon spent the most time (215 minutes).

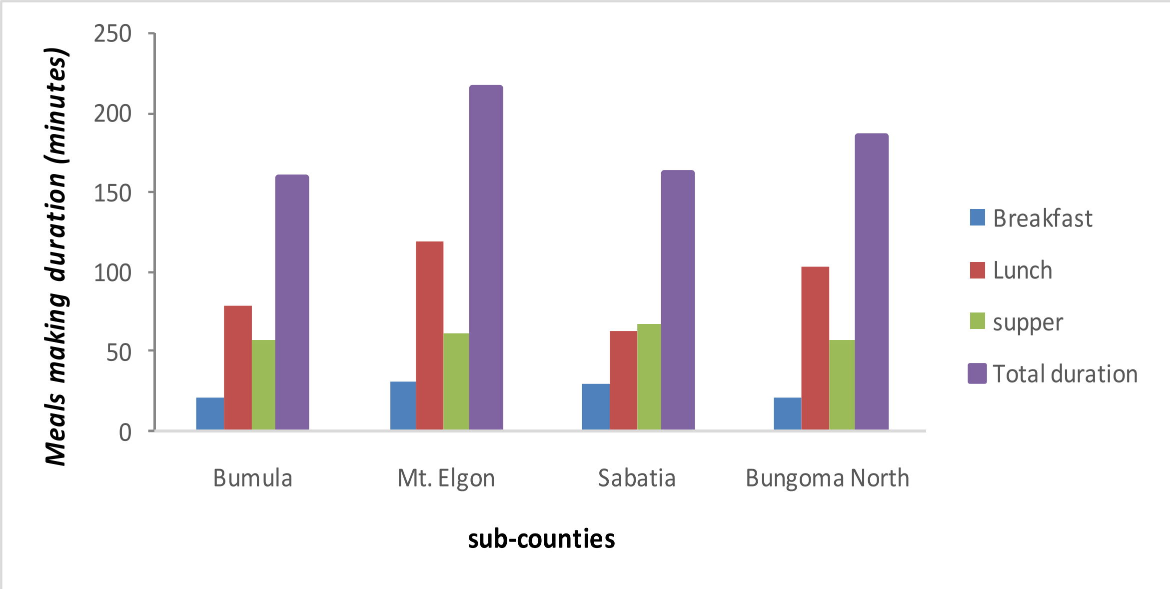

Figure 3.5 Households' duration of cooking meals in minutes for the cluster sub-counties

The choice of cooking energy has been associated with households' culinary behaviour that arises from cultural background, economic, and perception of food taste associated with energy type (Malla & Timilsina, 2014) of a household. Considering the close cultural proximity between households in Bungoma North and Bumula sub-counties to those of Sabatia, differences in durations of cooking and culinary behaviours were mostly associated with food and energy availability. Accessibility to energy sources has been observed to be a major driver of the type, quality, and quantity of food consumed in Sub-Saharan Africa (Sola et al., 2016).

3.3.5 Household socio-economic characteristics and energy choices

Figure 3.6 provides an insight on the relationship between gender, employment, and income status on one side and the choice of energy source for different meals. The use of firewood in breakfast preparation was 88% among female-headed households compared to 83% among male-headed and 88% and 54% for households without and those with formal employment. The proportion of households utilizing firewood for lunch preparation was 91%, 68%, 79%, and 90% among those without formal employment, those with formal employment, richer and poorer respectively.

Formal employment showed remarkable contracts among the key socio-economic welfare indicators across meals and cooking energy sources. This category depicted obvious evidence

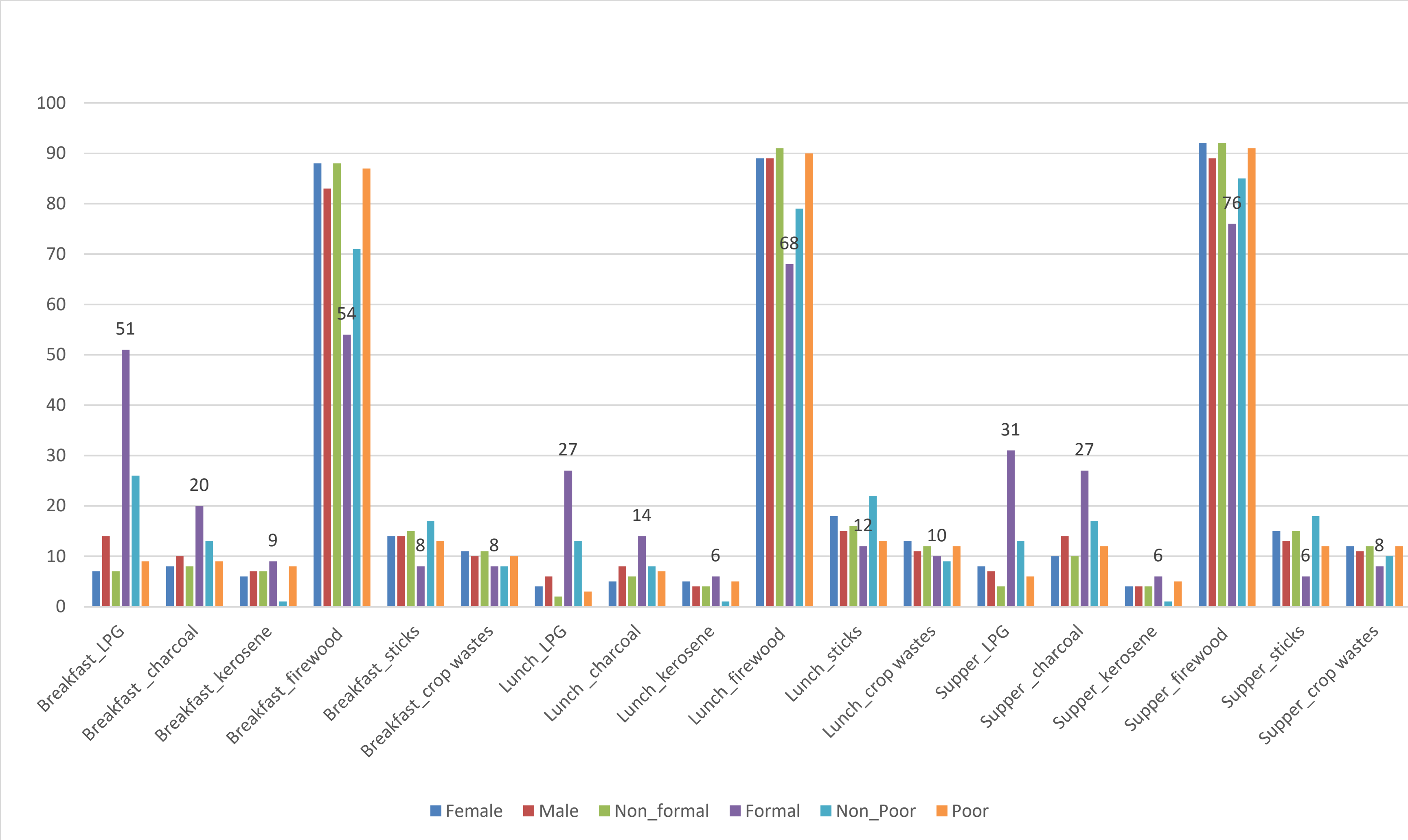

Figure 3. 6 Use of cooking energy sources for key meals by households in various socio-economic categories

of shifting from dirty to cleaner energy sources in conformity with the transition ladder (Bisu et al., 2016). Adoption of the clean (LPG) and transition (charcoal and kerosene) energy sources (Dash et al., 2018) was the highest across meal types while the use of dirty (firewood, twigs and crop wastes) was the lowest. The use of LPG as breakfast, lunch, and supper cooking energy source was by 51%, 27%, and 31% respectively for the households with their heads on formal employment. The use of charcoal among households with household heads on formal employment was 20%, 14%, and 27% for breakfast, lunch, and supper respectively. Lower proportions on the use of firewood for breakfast, lunch, and supper of 54%, 68%, and 76% respectively were associated with the category.

3.3.6 Monthly trends on household energy sourcing characteristics

Figure 3.7 shows the proportions of various energy sources used by households by months of a year. Biomass associated sources were the most used cooking energy types including firewood, twigs, maize wastes and charcoal, and sawdust. The liquefied petroleum gas (LPG) accounted for on average six percent in all the months. Firewood was the most popular energy source across the year with an average proportion of its reliance ranging between 59 and 71%. Despite the dominance of firewood across the months, a slight reduction was

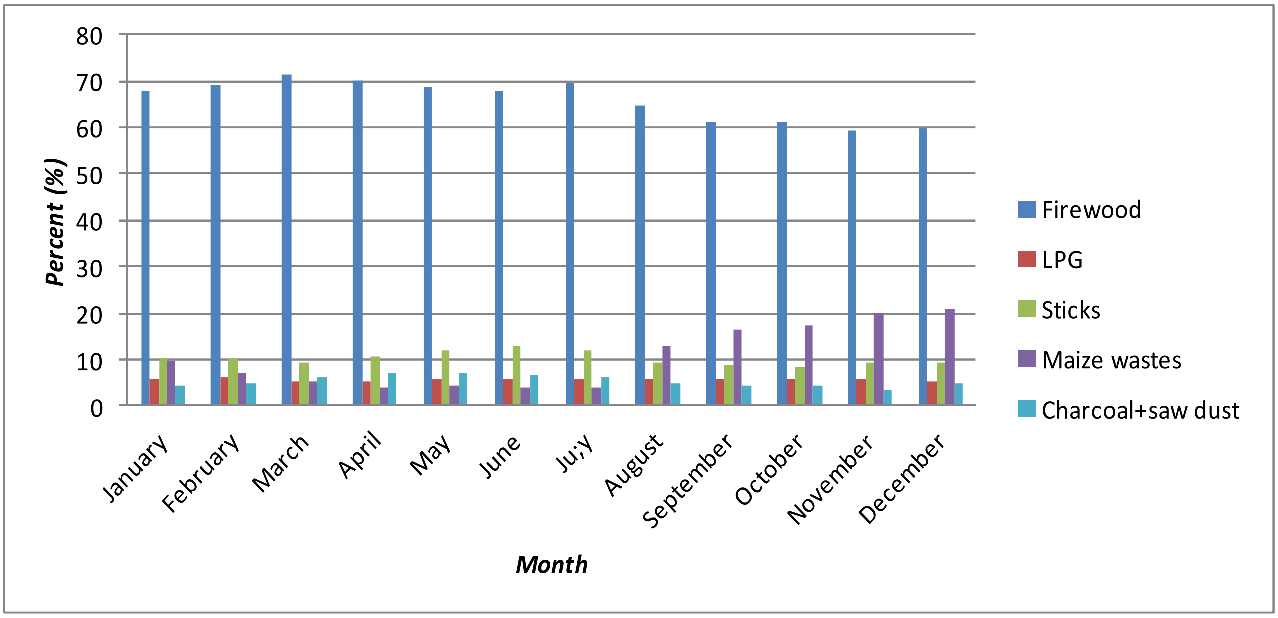

Figure 3.7 Western Kenya households' cooking energy sourcing by months

observed between August and January. The reduction coincided with a duration when dependent on maize wastes (maize stocks and combs) as cooking energy increased from 13%

to 21% between August and December. Duration of increased utilisation of maize waste as cooking energy coincides with duration associated with maize harvesting (Jaetzold et al., 2007). The outcome provides evidence of agricultural production enhancing the household's energy availability.

On average, stocks accounted for a tenth of cooking energy sources by households, however, a slight surge in reliance is observed between April and July. The proportion of charcoal and sawdust use as cooking energy sources rose in the same durations when reliance on twigs was higher. It also happens that, the same duration is very wet as it coincides with the long rains (Jaetzold et al., 2007). Communities in the region reported (*through focus discussion held in March 2018*) severe energy challenge which necessitated them to prune trees in October and November in preparation for using twigs over the next season of lean means. It is therefore observed that cooking energy choice among households has a pattern that is influenced by among other factors maize production and rainfall or weather seasons.

Figure 3.8 shows how households ranked the ease to access energy choices across the months. Generally, it was observed that only less than a tenth of all farmers considered themselves as being energy sufficient. The trends in the proportion of households, who were energy insufficient, had access concerns or sufficient had seasonal effects. Between April and July, a higher proportion of households (22% to 25%) reported insufficiency in accessing energy sources. The same duration had the least of those reporting sufficiencies in accessing energy at about three to four percent.

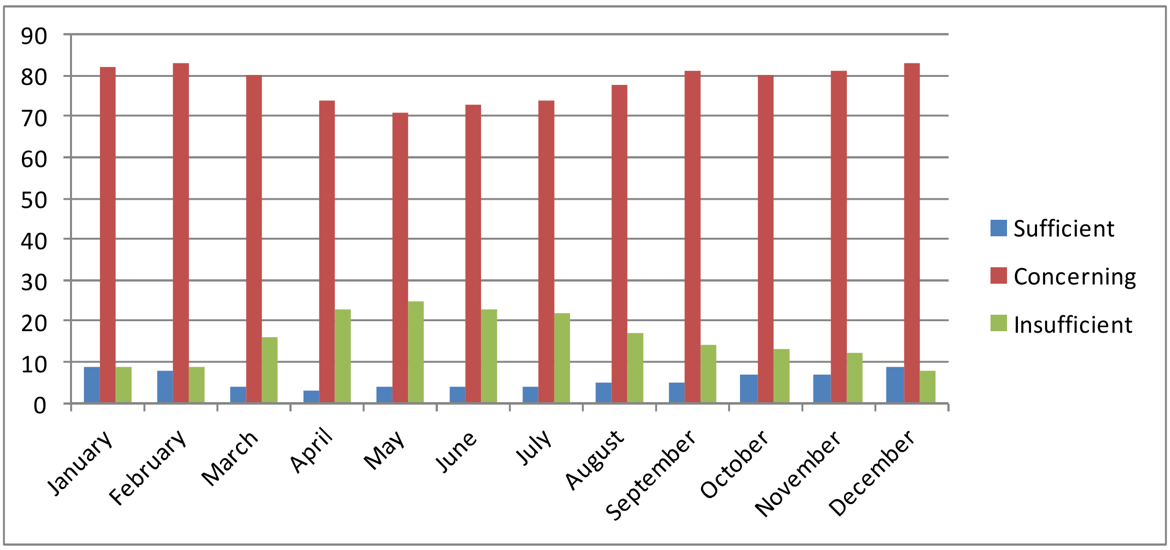

Figure 3. 8 Annual households cooking energy sufficiency trends in western Kenya

3.3.7 Households' food production and sourcing characteristics

Figure 3.9 shows how households rated their food security status in various months. The largest proportion of farmers was food insufficient or was surviving on amounts they considered concerning. Food security status was observed as having seasonal effects. Between January and June, only less than a tenth of all farmers were food sufficient. Sufficiency in food availability rose between 16% and 18% between August and December. From March to July the proportion of farmers that had insufficiency in food access ranged between 31% to 50%. This duration could be considered as hungry seasons (Fink et al., 2018) when there was severe food deficiency, prices for the staple were exorbitant and the farming households suffered severe financial shortages with high limitations for access to sources of earnings. Another major observation was the fact that at any one point even during the harvest seasons (Jaetzold et al., 2007) no less than a tenth of farmers in western Kenya had food sufficiency.

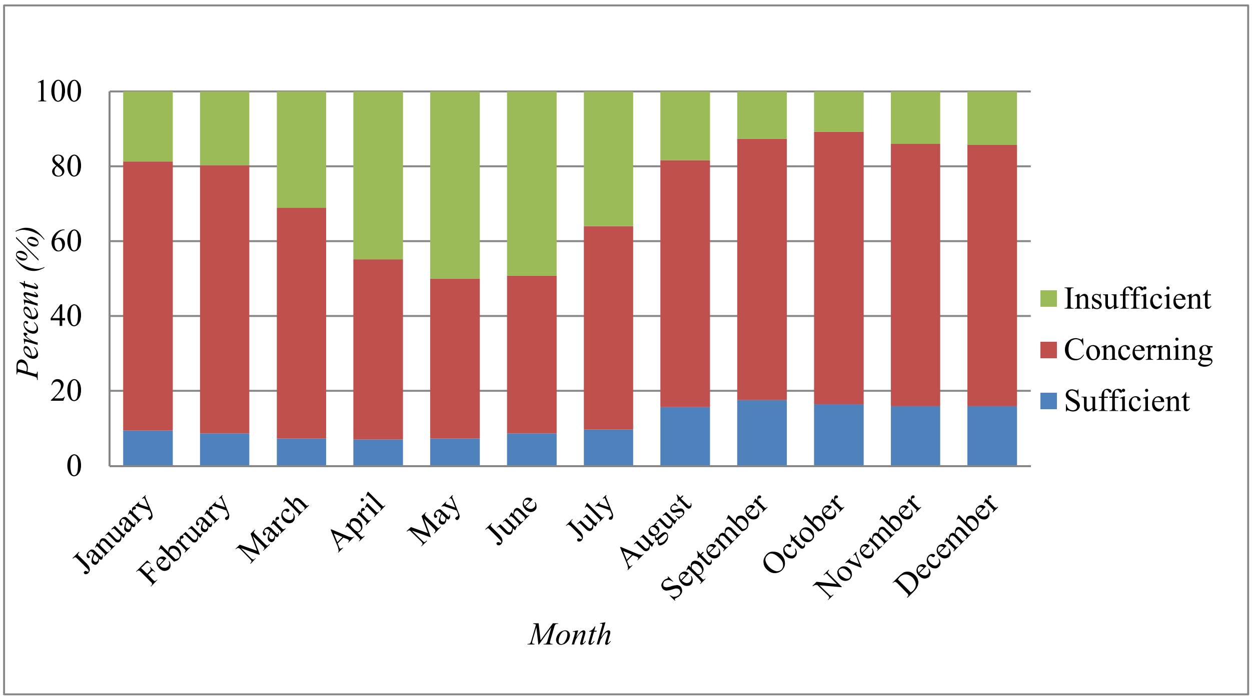

Figure 3. 9 Annual food sufficiency trends among farmers in western Kenya

Several production factors could be associated with the observed food security status of farmers. Low agricultural production is associated with failure to adopt high yielding technologies (Muzari et al., 2012), diminishing farming land sizes (Gollin, 2019), the ageing agricultural labour force (Guo et al., 2015; Rufai et al., 2018) and excess sale of subsistence outputs (Baiphethi & Jacobs, 2009: Fink et al., 2018) to meet financial needs. Factors hindering adoption of high agricultural production technologies included inputs' costs (Yigezu et al., 2018), inaccessibility of credit and insurance services (Sibiko et al., 2018), farmers' characteristics (Nkari & Kibera, 2016), poor information dissemination (Lukuyu et al., 2012) and low returns that failed to provide motivations for production.

Figure 3.10 shows the trends on the average amount of maize used by households, the proportion of own production used; the proportion of maize purchased for household use; and the use of other non-maize staples in various months. On average, per household's monthly maize consumption ranged between 46 and 52 kg. Low consumption was observed between April and June when about 47 and 46 kg of maize were utilised by households per month, respectively. Around the same duration, farmers were purchasing the highest proportion of maize averaging about 40%. Higher household maize consumption of 52kg was reported in November and December, a duration that coincided with higher reliance on own production (above 85%) and low purchases (less than 15%).

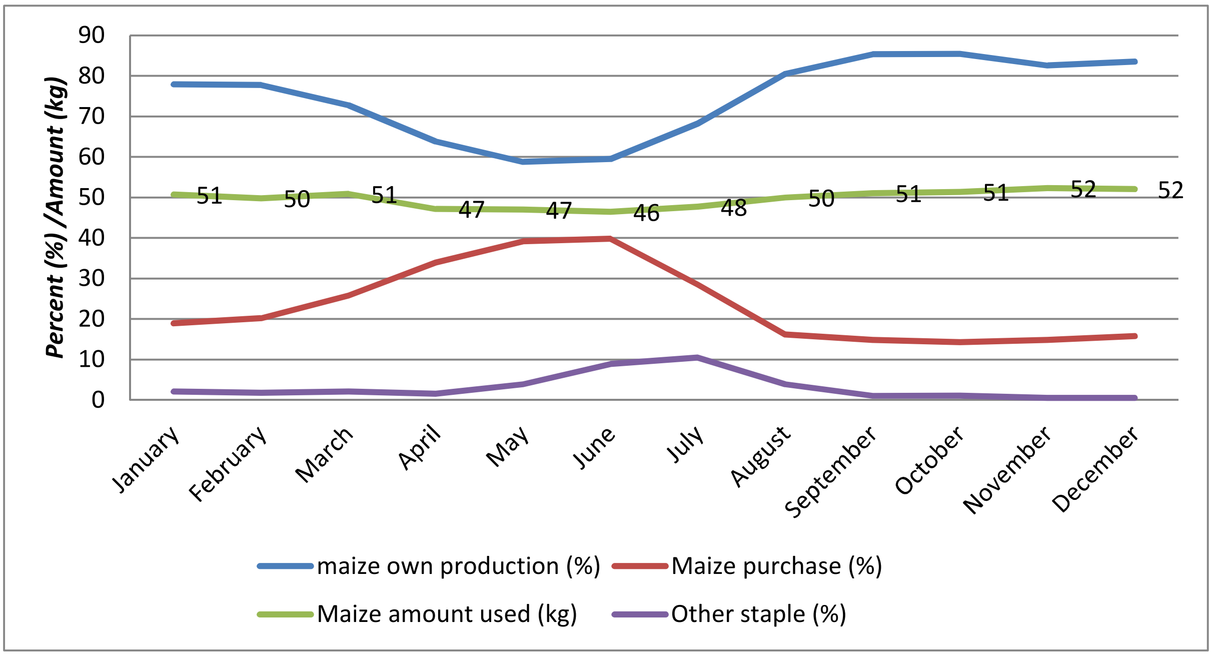

Figure 3. 10 Maize production, purchase, use and diversification among households

Overall own maize production accounted for more than a third of household consumption between January and March, and July to December. The locus of the proportion of maize purchased mirrors that of own maize production-consumption. Durations of higher maize purchases coincided with those of reported insufficiency and vice versa. Over the year, the shift to non-maize staples was observed to be minimal at less than 10%. During the maize harvesting period and a short while after (September to December), utilisation on non-maize staples was at the lowest and approached zero. However, afterwardsutilisation of non-maize staples rises reaching a high of 10% in June and July.

Figure 3.11 shows food sufficiency from own agricultural production among smallholders. On average sufficiency in food demand through own production accounted for 74% for the sampled sub-counties. In Sabatia, farmers were only able to meet slightly higher than half of the household staple food demand with the other portion purchased from the market. The observation on households' ability to meet food demand is close to that reported (Rao et al., 2015) for the entire county of Vihiga which associated maize sufficiency to 43% of households.

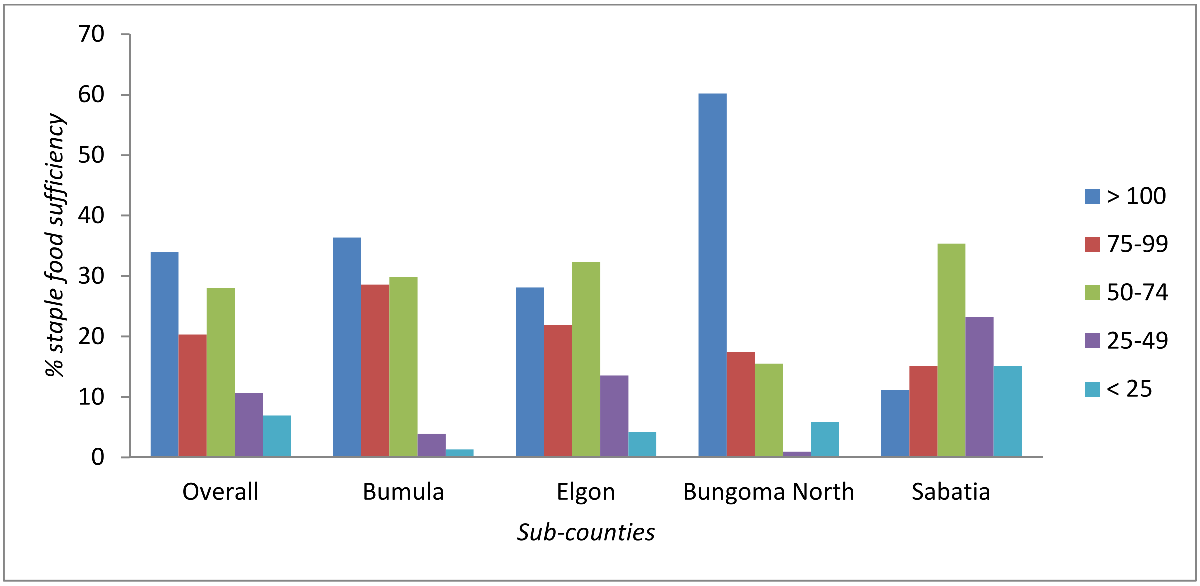

Figure 3. 11 Sufficiency in food production among smallholder farmers in sub-counties of western Kenya

In Bungoma North, only about an eighth of the staple food demand was acquired by resulting to purchase. The reported staple food access levels through their production point to a dire agricultural based livelihood system. Subsistence farming system production prioritises own food production sufficiency with the excess marketed to provide income to meet the other households' financial needs. Without farming households overcoming the initial agricultural production hurdle of meeting their food demands, it would be extremely difficult for the farming systems to provide sufficient income to address poverty reduction.

3.4 Conclusions

Despite the sampled clusters sub-counties having prominent heterogeneity in agro-ecological characteristics expected to denote differences in socio-economic characteristics, agricultural and energy sourcing attributes, a number of similarities were observed. Differences in socio-economics, agricultural, and energy sources access features were observed across the sub-counties that could not be mostly concomitant with the trends on net-evapotranspiration aspects of agro-ecological zones (Jaetzold et al., 2007).

Firewood was the most popular source of household cooking energy in all the sampled sub-counties for all the key meals. However, the use of firewood reduced slightly in the case of breakfast across the sub-counties from the reliance of about 90% in case of supper. Diversification of energy sources for cooking firewood to the cleaner transition energy was more pronounced in the case of breakfast preparation compared to other meals. Formal employment was observed as a major driver of the transition to cleaner energy across key meals compared to other socio-economic factors evaluated including household gender and the richer and poorer household based on the consumption expenditure. Higher usage of LPG was reported (51%) among the formal employed for breakfast preparation. The adoption of LPG among the formal employed for lunch and supper preparation was higher also at 27 and 31 percent respectively. The use of firewood as a cooking energy source reduced substantially for all meals in case of the formal employed compared to other socio-economic categories.

Preparation of varied key meals was associated with durational differences with lunch taking the most time while breakfast took the least. However, in Sabatia preparation for lunch and supper took an almost identical cooking period. Duration utilised to prepare varied key meals differed across sub-counties with households in Mt. Elgon allocating most time for cooking.

Higher levels of energy and food insecurity were observed in the sampled sub-counties. Across the months of the year, sufficiency in energy sourcing was reported by less than a tenth of farming households. Between April and July, a higher proportion of households (above 20%) reported to have been cooking energy insufficient and the lowest proportion of households (<5%) reported sufficiency in cooking energy. Higher levels of energy sources poverty were reported in May with the highest (25%) ranking it as insufficient, and others rankings (concerning and sufficient) levels being the lowest. Energy sourcing access depicted seasonal patterns with months coinciding with those when maize was being harvested associated with more households recording energy sourcing sufficiency and concerning and lower levels of insufficiency. Inreased in the proportion of maize wastes (cobs and stalk) usage among households coincided with months when challenges of energy sourcing decreased.

Ranking of food availability as sufficient, concerning, and insufficient depicted a seasonal pattern that was coincided with energy sources access pattern. Low levels of food sufficiency were reported across the months of a year and ranged between seven to 18% of households. Lower levels of food sufficiency were reported between March and May with only seven percent of households approving this desired ranking. May was associated with the high levels of food insecurity while October depicted the months of higher food security among the sampled sub-counties. Households responded to lean staple food durations by reducing consumption of maize, buying more from the market, and diversifying to other non-staples foodstuffs. Higher dependency (85%) on own maize production was reported in September and October while greater proportions (40%) of households bought maize in May and June.

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CHAPTER FOUR
DETERMINANTS OF COOKING ENERGY CHOICE AMONG HOUSEHOLDS IN WESTERN KENYA

Abstract

Increased population pressure on agricultural land among the smallholders has not only had detrimental effects on food production but also access to biomass cooking energy. Moreover, harvesting of vegetation for biomass energy has degraded landscapes and depleted the biodiversity critical for supporting agricultural production. Understanding determinants of cooking energy choice among smallholders will facilitate the formulation of policies that could revamp agriculture and improve households' welfare through sustainable development goals. Using a database of 400 smallholders collected in the first quarter of 2018 determinants of cooking energy choice was evaluated. The specific objectives of the study were to evaluate the determinants of cooking energy choices among households for various essential meals; to incorporate agricultural production factors into understanding cooking-energy choices, and to assess energy use homogeneity among various socio-economic and agro-ecological clusters. Firewood was the most preferred cooking energy choice with more than 90% of households using it for each of meal types. A multinomial logit model outcome showed factors that increased the likelihood of households' preference for LPG in relation to firewood to include per capita consumption expenditure ($P \leq 0.05$) and formal employment for the household head ($P \leq 0.05$). Households enjoying credit facilities ($P \leq 0.05$) and those with a higher proportion of members being adults ($P \leq 0.05$) had less likelihood of preferring LPG in relation to firewood in breakfast preparation. Households who were facing a higher cost of firewood and those relying on their farm for biomass cooking energy were more likely to prefer twigs rather than firewood for breakfast preparation. Households in the sampled area were found to be homogeneous on cooking energy sourcing behaviours. Study outcomes were consistent with other concepts associated with cooking energy usage, including the transition energy ladder and energy stacking.

4.1 Introduction

Energy for cooking and heating is a critical human basic need. Its acquisition has financial and labour cost implications, and hence economic repercussions to the household's resources. The type of energysource chosen by a household is important for many reasons. The reasons include depletion of household's financial resources; labour trade-offs from other productive activities; deforestation and degradation of biodiversity; and critical for households' welfare. Reviews of Africa's cooking energy utilisation show that large proportions of rural households in Sub-Saharan Africa rely on biomass energy for cooking and heating (Lusambo, 2016; Mperejekumana et al., 2021; World Bank, 2014). This implies that time and effort that would otherwise go to agricultural production is spent in gathering and production of biomass energy (Popp et al., 2014).

Another concern, for policymakers, is households' energy poverty status and how it affects agricultural production. Moreover, some interest in households' welfare and cooking energy sourcing has been revitalised with the formulation of United Nations Sustainable Development Goals (SDG) also referred to as 17 Global Goals (UNEP, 2019). The SDG number 7 addresses affordable and clean energy, it targets ensuring access to renewable, safe and widely available energy sources for all by 2030. Critical analysis of the SDG's precursor, the millennium development goals (MDG) showed that despite the agenda failing to consider energy among its key development targets, energy poverty had repercussions on all the eight goals (Rehfuess et al., 2006).

In Kenya, firewood is the most popular energy source accounting for about 90% of biomass energy used (Rahnema et al, 2017: UNEP, 2019). While opportunities for its procurement from the market exists (Ndegwa et al., 2020) a large number of households are involved in its production through farm forestry or gathering from existing proximity biomes (UNEP, 2019). Biomes, where households collected their firewood, include forest, woodlands, bushland, shrubland and farmlands. Time used for firewood fetching represents opportunity cost and hence has economic implications estimated at three percent of developing counties' gross domestic product (UNEP, 2019) thereby affecting households' resources available for agricultural production.

Although the relationship between energy sourcing and agricultural production has been overlooked by researchers in the two respective fields, instances of households' energy choices and demand affecting agricultural production could be highlighted. Attributes associated with cooking durations and production of biomass to be used for cooking among introduced rice varieties were ranked high for adoption ahead of yield in Burkina Faso (Adesina & Baidu-Forson, 1993) and Sierra Leone (Adesina & Zinah, 1995). Tea farmers have been reported to overlook recommendations related to pruning seasons, heights, cycles and use of prunings in their efforts to meet biomass energy demand (Anonymous, 2002). The pruning regime adopted by farmers as they attempt to maximise firewood returns from tea bushes increases the plant's diebacks, stem canker and hypoxylon stem rots (Lehmann-Danzinger, 2000), all diseases of economic importance as they affect crop productivity (Anonymous, 2002). Loss of biodiversity resulting from flora clearance for firewood has impacted available browse for bees, livestock and pollination effectiveness (Hasnat et al., 2019) which are critical in agricultural productivity.

Clearing vegetation to meet the biomass energy demand has had negative effects on the agro-ecosystem including soil erosions; denudation of the ecosystems' ability to sequestrate greenhouse gas, and desertification. Other indirect effects of vegetation removal on farmers include pollution of water bodies leading to negative consequences to fishery development, water-borne diseases and increased challenges in accessing water for domestic use and agricultural production (Hasnat et al., 2019). The use of biomass energy sources has been associated with detrimental health effects to users including deaths (Frings et al., 2018) thereby impacting the agricultural labour force.

In some cases, farmers have participated in biomass energy production through farm forestry, agroforestry and biofuel farming (Sharma et al., 2016). Together with the supply of biomass energy for household consumption, the growth of trees has other benefits including diversification of income sources for farmers and an improved environment. Trees improve the environment through absorption of carbon dioxide from the atmosphere; soil nutrient replenishment and conservation; and wind control among others (Sharma et al., 2021). Notwithstanding the benefits, trees farming competed with food production when smallholders allocate land to tree management instead of farming food crops. With land limitation being one of the major bottlenecks in food security and welfare among smallholders farmers (Popp et al., 2014), competition for land presented by tree planting would worsen food security. Moreover, efforts by smallholders to source firewood divert labour from agricultural production to energy supply. On the other hand, the production of staple crops for food security is associated with biomass by-products that could be used to meet households cooking energy demand (Gutierrez et al., 2022). Another critical policy concern for both food production and household energy experts is if the levels of farmers' earnings from agriculture do affect the cooking energy choice. It is therefore imperative to understand the economics of cooking energy to address agricultural production.

The specific objectives of this paper were i) to evaluate the determinants of cooking energy choices among smallholder farmers for various essential meals; ii) to incorporate agricultural production factors into understanding cooking-energy choices, and iii) to assess energy use homogeneity among various socio-economic and agro-ecological clusters.

4.2 Methodology

4.2.1 Data Sources

A survey research design as described in Chapter 3 was adopted as the primary data source for a cross-sectional study executed between January and March 2018. The closed and open-ended questionnaire used as a tool in data collection had four modules that included questions on households' i) cooking energy consumption; ii) socio-economic characteristics, and iii) agricultural production characteristics.

The socio-economic information collected was associated with the household head; the household and the households' environment. Among the household head information gathered included that on levels of formal education achieved; gender, age, experience farming, and formal employment status among others. Some of the households' characteristics information collected comprised data on household size, the proportion of adults, proportion of adults, amount of land available for settlement and production, weekly consumption expenditure, the proportion of maize consumed that was produced by household, and if household held a title deed to the land owned. Household environment information was mostly captured through the sub-county sampling for the study. Each of the sub-county sampled represented characteristics on agro-ecological; the overall biomass energy accessibility potential; altitude and weather factors.

The cooking energy characteristic modules had addressed issues about cooking energy choice for various key meals including breakfast, lunch and supper. In conformity to both the energy ladder and the energy stacking theories, households were expected to have multiple choices including cow dung, agricultural wastes, firewood, charcoal, kerosene, LPG and electricity. Other cooking energy associated questions included the distance to sources of the energy options used.

4.2.1 Analytical model

This study derived its methodology from the agricultural household model approach (Barnum & Squire, 1979; Taylor & Adelman, 2003) and the theoretical framework presented on the energy-agricultural model (Muller & Yan, 2018; Zi et al., 2021). However, Kenya cooking energy utilisation is explained by both the energy shift ladder and energy stacking conceptual model (Osiolo, 2009). The challenge of energy quantification and that of establishing the shadow prices in rural areas leads to the strength of preference models (Taylor & Adelman, 2003) over the AHMs (Muller & Yan, 2018). The choice of the model for this analysis was determined by some factors including the study's objectives, the data being analyzed and the advantages associated with the candidate models. The study was a choices evaluation, which had the independent variable is categorical. The study objective and database type meant the most relevant choices of models were two including the MNL and multinomial probit (MNP) model. Both the MNL and MNP are multivariate multiple models which could be applied with at least two dependent variable and a multiple of independent variables (Hildalgo & Goodman, 2013), they are also dicrete choice models that could be used to predict choice or preference for alternate options (Nugraha, 2019).

Despite MNP being more favoured due to its relaxation of the independence of irrelevant alternative (IIA) assumptions (Bayaga, 2010), the MNL was used. First, despite MNL having a challenge of violating the IIA assumptions, studies have shown (Dow & Endersby, 2004; Kropko, 2008) that MNL nearly always provides more accurate results than MNP, even when the IIA assumption is severely violated. Other advantages of MNL include its simplicity; it is more robustness to violations of assumptions of multivariance normality and equal variance-covariance matrices; its similarity to linear regression with easily interpretable diagnostic statistics; failure to assume a linear relationship between the dependent and independent variables; and the independent variables used need not be an interval (Kropko, 2008). MNL is more stable, an efficient estimator and offers more intuitive answers to theoretical questions (Dow & Endersby, 2004).

The MNL model assumes that if there is a k categorical outcome without loss of generality the base outcome is 1. The probability that the response for the jth observation is equal to the ith outcome is

$$\mathrm{p_{ij}} = \Pr(\mathrm{y_j} = i) = \begin{cases} \frac{1}{1+\sum_{m=2}^{k} \exp(x_j\beta_m)}, & \text{if } \mathrm{i} = 1 \\ \frac{\exp(x_j\beta_m)}{1+\sum_{m=2}^{k} \exp(x_j\beta_m)}, & \text{if } \mathrm{i} > 1 \end{cases} \qquad (4.1)$$

where $\mathrm{x_j}$ is the row vector of observed values of the independent variables for the *jth* observation and β_m is the coefficient vector for outcome m.

$$\ln L = \sum_j w_j \sum_{i=1}^{k} I_i(y_j) \ln p_{ik} \qquad (4.2)$$

Where $\mathrm{w_j}$ is an optional weight and

$$\mathrm{I_i}(y_i) = \begin{cases} 1, \text{if} y_j = i \\ 0, \text{otherwise} \end{cases} \qquad (4.3)$$

4.2.2 Empirical model

The MNL equation being regressed could be simply represented as

$$y_j^* = \beta_j x_{ij}^{'} + \epsilon_{ij} \qquad (4.4)$$

Table 4.1 Description of the dependent variables

Dependent variables/ Energy	*Description of the variable*
Liquified Petroleum Gas (LPG)	Cleaner energy as per the transition ladder. The desired output for this research
Others	Represents the transition energy sources (charcoal and kerosene).
Firewood	A woody biomass energy source mostly entails substantial removal of biomass and deforestation. The diameter is above 3 cm for each side.
Twigs	Herbaceous biomass energy sources include twigs from farm forestry, biomass die-backs and leaves (Geremew *et al.,* 2014*)*. Mostly collected by children and do not necessarily result in deforestation. Either side of a stick is not hewed and is less than 3 cm in diameter.
Crops wastes	By-products of maize include stocks and cobs. The direct link between agriculture and energy.
Cleaner sources	Including transition energy sources and LPG used in case of lunch and supper.

The log pseudolikelihood, y_j^* represents a matrix of cooking energy choices of energy utilised for breakfast, lunch and supper as shown in Table 4.1. $_j$ could take the value representing each of the cooking energy choices including LPG, firewood, twigs, agricultural wastes and the transition energy sources. β_j is a vector of the parameters, whereas $x_i^{'}$ is a matrix of explanatory variables of socio-economic characteristics associated with household head, the household, and community and agricultural environments. ϵ_{ij} is the error term while $_i$ represents individual households. Table 4.1 shows the dependent variables representing each of the cooking energy options.

4.3 Results and discussion

4.3.1 Households' characteristics and cooking energy choices

Table 4.2 shows the household head characteristics that were postulated to influence the adoption of various cooking energy sources for rural households. Household heads are critical in household decision making in multiple aspects, energy consumption included (Mperejekumana et al., 2021). Household heads' characteristics play an important role in determining the decision made in a family. Among household head characteristic variables, gender and formal employment were dummy variables. Male household head and participation in formal employment were considered as 1 and 0 if otherwise. Other variables included household head age, experience farming and years of education.

Table 4. 2 Household head socio-economic characteristics of rural households in western Kenya

Household head Characteristics	Mean	Std. Dev	Min	Max
Household head gender	0.79	0.42	0	1
Household head age (years)	49.82	15.53	20	93
Farming experience (years)	20.84	15.12	1	75
Formal employment	0.13	0.34	0	1
Formaleducation achievements (years)	9.56	3.75	1	16

Table 4.3 shows households' socio-economic characteristics that were postulated to determine the household's choice of cooking energy. These factors included the number of people in a household, the household's average education levels, the proportion of females and adults in a household. A household's socio-economics' characteristics provide the socio-cultural environment a household head operates in thereby anchoring the decisions for production, resources availability and demand, and the family unit's developmental aspiration. Researchers have included household socio-economics' characteristics on studies related to agricultural technologies (Rehman et al., 2013), agricultural yields (Baffoe-Asare et al., 2014; Oluwatusin & Shitu, 2013), enterprise diversification (Windle & Rolfe, 2005), poverty levels (Mitiku, 2014), energy demand and source choices (Makonese et al., 2018) among others.

On average, a household in western Kenya had 5.3 individuals with a standard deviation of $\pm$ 2.1. The largest households had 13 members with the least having a single individual. The size of a household defines the amount of food to be cooked thereby influencing the efforts and economics of energy source choice. Smaller households have been observed to adopt cleaner market purchased energy choices compared to large families (Carrión et al., 2018). On average females and adults accounted for 44% and 58% of the members of a household. These Households' structural characteristics are important on domestic chores' allocations and hence impact the decision for adopting cooking energy sources (Makonese et al., 2018). Per capita, formal education duration illustrated that on average households members had completed covering primary education based on the education system in Kenya.

Table 4. 3 Households socio-economic characteristics of rural households in western Kenya

Characteristics	Mean	Std. Dev	Min	Max
household size (no,)	5.26	2.09	1.0	13
Proportion of adults (%)	0.58	0.25	0.09	1
Proportion of female in a household (%)	0.44	0.28	0.13	1
Household average formal education (years)	8.18	3.05	1	17.83
Household cumulative educ. (years)	34.96	18.00	1	107.0
Household enjoying credit facilities	0.23	0.42	0.00	1
Number of houses in a household	1.95	0.89	1.00	6
Food production proportion (%)	73.29	27.39	0	100
Daily per capita expenditure (KES)	55.25	40.57	6.35	476.19
Sabatia	0.26	0.44	0	1
Mt. Elgon	0.27	0.45	0	1
Bumula	0.21	0.40	0	1
North Bungoma	0.26	0.44	0	1

On average every household reported having two houses. Seventy-three percent of households sufficiently met their staple (maize) annual demand through their production. Some households relied entirely on purchased staple food while others were able to produce sufficient to cover their annual demand. Geographical locations of sampled clusters presented differential characteristics or environments which affect both agricultural and energy production, as well as consumption. Differentials in energy production and consumption, agricultural production, economic welfare and dietary behaviours were likely to influence the choice of cooking energy. Each sub-county was considered as a dummy with a value of 1 when it was being considered and a 0 if otherwise. Locational factors have been highlighted as influencing energy access behaviour and choice in many studies (Alem et al., 2016; Chen et al., 2016; Mwaura et al., 2014).

The incorporation of agricultural characteristics in an energy choice model was guided by the fact that rural households were considered to make their decision on production and consumption for agricultural and energy commodities simultaneously (Chen et al., 2016; Muller & Yan, 2018; Taylor & Adelman, 2003). The simultaneous decision making for production and consumption in rural households, coupled with imperfect markets for the produced and consumed goods are the pillars for the agricultural households' models (Barnum & Squire, 1979; Taylor & Adelman, 2003). The fact that agricultural production and biomass energy sourcing use similar factors of production including labour and capital (Poppet al., 2014) led to the proposition of interrelationship. Furthermore, agriculture is a key production activity influencing the economic welfare through enhanced income of the farming household (Davis et al., 2017; Rotich et al., 2017) which consequently impacts the capacity and aspiration on the choice of cooking energy (Makonese et al., 2018). Activities geared towards increasing access to energy including bioenergy, agroforestry and the use of agricultural wastes have influenced agricultural production (Córdova et al., 2018).

Table 4.4 shows the households' agricultural characteristics that were postulated to affect cooking energy sources' choices.

Table 4. 4 Agricultural characteristics of rural households in western Kenya

Characteristics	Mean	Std. Dev	Min	Max
Agricultural livelihood support (agricont)	77.54	27.85	0	100
Membership to farmers group (farmergrp)	0.25	0.43	0	1
No. livestock enterprises (livesente)	1.89	0.87	0	3
2017 Maize production (kg)	2194.59	11986.49	0	40500
Land owned (ha)	2.43	3.17	0.125	20
2017 agricultural investment (KES)	20474.5	30245.35	110	300000
Number of Fruit trees	10	24.39	0	10.3
Number of Trees	127	259.03	0	2000

The dummy variable included membership to farmers' groups. Other factors considered include an agricultural contribution to household welfare, maize acreage, levels of production and yield achieved in 2017 and the number of trees managed by a household.

Energy associated factors were expected to influence the cooking energy choice by households. Table 4.5 shows the summary of descriptive statistics for energy associated factors that were postulated to influence the choice of cooking energy among households. Energy associated dummy variables included the adoption of solar panels, improved cooking stove, firewood collection restricted to a household's owned farm and if the household was conscious of warming the house environment as it decided on cooking energy choice. A positive response to each of the highlighted dummies was allocated a 1 and if otherwise 0.

Other variables include distance covered in search of firewood, duration spent per outing in gathering firewood, cost of firewood utilised per week, number of household members who were routinely involved in firewood gathering and number of houses owned and being utilised by a household. These variables are associated with efforts of accessing and availing biomass cooking energy, which has been reported to influence cooking energy choice among rural households (Zi et al., 2021).

Table 4.5 Energy associated characteristic of rural households in western Kenya

Characteristics	Mean	Std. Dev	Min	Max
Distance to firewood gathering	0.55	1.06	0	12
Own farm firewood reliance	0.58	0.49	0	1
Members gathering firewood (no).	1.34	0.96	0	6
Adoption of solar energy technology	0.52	0.50	0	1
Conscious of warming house environment	0.21	0.41	0	1
Adoption of improved cooking stove	0.42	0.49	0	1
Weekly firewood cost	341.23	310.82	0	1400
Duration per outing of firewood (min)	79.21	82.37	0	480

4.3.2 Determinants of breakfast cooking energy choices

A multinomial logit model regression results are shown in Table 4.6. Firewood was the cooking energy widely preferred by the households for breakfast preparation and was the base outcome in the MNL analysis. The Likelihood Ratio (LR) Chi-Square (LR chi2), Prob>chi2, the McFadden pseudo-R-squared (Pseudo R^2) and the log-likelihood were 205, 0.00, 0.27 and -270.6 respectively. The MNL model converged at -270.6 which was the log-likelihood of the fitted model derived when the difference between successive iterations was very small. The observed McFadden's pseudo-R-squared of 0.27 was accepted as it was in the range of 0.20 and 0.40. However the Pseudo R-squared reported was not interpreted as the R-squared associated with the linear ordinary least square (OLS) model as the MNL's only represented the proportionate increase in the model fit as a result of the inclusion of predictor variables (Donencich & McFadden, 1996). Prior to running the MNL, a multicollinearity tests of the variables were undertaken through a post regression Variable Inflator Factor (VIF) test which showed the variables as being modestly correlated (Kim, 2019) as their VIF values ranged between 1.16 and 2.73 with a mean of 1.62. The results of the VIF are as shown in the Appendix C2. The modest correlation outcome was accepted as all the VIF values were below 5.

Household access to credit, involvement informal employment, the increased proportion of adults and per capita expenditure were significant ($P \leq 0.05$) in influencing the likelihood of households' preference of LPG for breakfast preparation compared to firewood. The increased likelihood of preference of LPG associated with household head involvement informal employment was attributed to income earned as wage.

This observation is consistent with the energy ladder concept which relates preference of cleaner energy including LPG in relation to solid energy sources to enhanced welfare and income (Muller & Yan, 2018). Formal employment was associated with extra income which was received as monthly wage. With the extra income, the household could afford to invest in both the LPG and its associated equipment including gas cylinders and burners (Debbi et al., 2014; Mwaura et al., 2014). Formal employment in the study area presented a unique scenario as far as income was concerned in that the targets were rural residents involved in agricultural production through subsistence farming system fully dependent on rain (Wortman & Eledu, 1999) with rewards mostly in the forms of a harvest for food or sales of the extras produce (UBoS, 2010; Wortman & Eledu, 1999). Moreover, the returns in terms of harvests from the annual crops' agricultural system are poorly distributed as it is only received once (in case of a single season) and rarely twice a year (two cropping seasons) with the household having the difficult task to budget for an entire year's necessities. Some of the household's necessities include fuel, foodstuff, education of the children, medical expenses, reinvestment in agriculture and leisure. Formal employment also boosts the perception of an individual as being in a unique social class among the rural society, therefore increasing the

Table 4. 6 Multinomial Logit Regression outcome on the households' determinants of breakfast cooking fuel preference

Breakfast energy	LPG_gas		Twigs		Agricultural wastes		Transition energy	
Variables	Coeffic ient	Std.err	Coeffi cient	Std.Err	Coeffici ent	Std.err	Coeff icient	Std.err
Log_ Household head age (years)	3.47	1.59**	-0.33	0.84	-1.16	0.78	-0.58	0.87
Sqrt_proportion of female	1.23	2.42	0.90	1.24	0.06	1.48	-2.79	1.35**
Sqrt_duration per outing of firewood (min)	0.01	0.08	0.02	0.06	-0.01	0.05	0.02	0.06
Sqrt_2017 agricultural investment (KES)	0.00	0.01	0.00	0.01	0.00	0.00	-0.01	0.01
Sqrt_2017 Maize production (kg)	-0.01	0.02	0.01	0.01	0.00	0.01	-0.01	0.02
Sqrt_Weekly firewood cost (KES)	-0.04	0.04	0.11	0.03***	0.04	0.02	0.01	0.03
Sqrt_ Distance to firewood gathering	-1.23	1.16	0.45	0.55	-1.31	0.62**	0.31	0.57
Log_ daily per capita expenditure (KES)	1.81	0.66***	-0.18	0.47	0.63	0.39	-0.04	0.41
Adoption of improved cooking stove	1.18	0.84	-0.69	0.55	-1.22	0.52**	0.68	0.51
Conscious of warming the house	-0.68	0.82	0.12	0.58	1.16	0.49**	-0.42	0.63
Number of houses in a household	-0.24	0.47	-0.79	0.34**	0.13	0.25	0.05	0.33
Adoption of solar energy	0.99	0.83	0.22	0.52	0.48	0.46	0.24	0.51
Membership to farmers group	-4.98	1.71	-1.63	1.12	-0.91	0.82	-2.88	1.10***
Household enjoying credit facilities	0.02	0.01	1.45	1.17	0.42	0.80	2.11	0.98**
Own food production proportion (%)	-0.02	0.02	-0.02	0.01**	0.01	0.01	-0.01	0.01**
Own farm firewood reliance	-0.92	0.71	1.94	0.60***	0.05	0.51	0.38	0.56

Members gathering firewood (no)	-0.92	0.71	-0.31	0.30	-0.28	0.25	-0.58	0.40
Household head years of formal education	0.06	0.11	-0.08	0.08	-0.03	0.07	-0.05	0.08
household size (no.)	-0.45	0.32	-0.09	0.17	0.38	0.14***	-0.08	0.16
Household head gender	2.11	1.23	0.21	0.65	-0.52	0.53	0.21	0.69
Household head formal employment	2.03	0.87**	0.94	0.93	-0.17	0.79	1.11	0.75
Proportion of adults (%) propadults	-5.99	2.53**	-0.03	1.25	1.11	1.11	0.55	1.23
Sqrt_ Land owned (ha)	0.86	0.61	-0.81	0.54	0.28	0.33	-0.04	0.51
_cons	-21.09	7.29	0.84	3.76	-3.68	3.46	3.35	3.69
Prob> chi2 = 0.0000	Log likelihood =-270.14							
LR chi2 (92) 205.07	Pseudo R^2 = 0.3748							

preference for clean energy (Muller & Yan, 2018) as a pride. Desire for a household to spend a short duration in preparation and ensuring the formally employed punctually partake breakfast at home together with other family members could also drive the preference of LPG.

Households accessing credit were observed to be less likely to prefer LPG than firewood, an observation contrary to expectation as elsewhere access to financing facilities has been linked to improved welfare (Rehfuess et al., 2006) which consequently led to clean energy adoption (Mperejekumana et al., 2021). Borrowing in the study area was linked to high levels of austerity, hence associated with a deficiency in finances that credit was restricted to more basic needs rather than investing in the energy transition. Accessibility to credit has been considered as an important component that increases the perception of affordability of the LPG and its implements (Quinn et al., 2018). Elsewhere access to credit increases the household capacity to invest beforehand and later pay through the future streams of income, especially for the prioritised commodities. However, the access to credit must be accompanied by the assurance of expected income.

Households with a higher proportion of adults were less likely to prefer LPG compared to firewood. This outcome of adult proportion hindering preference of LPG and other clean energy is consistent with other studies including (Brouwer et al., 1997; Mwaura et al., 2014). A high proportion of adults is a pointer to access to labour that could be harnessed for both firewood fuel sourcing and meals preparation.

Per capita income presented by expenditure was associated with more likelihood of a household preferring LPG than firewood in breakfast preparation. The observed relationship between income and preference for LPG was consistent with other studies (Baiyegunhi & Hassan, 2014; Ozoh et al., 2018), the transition ladder (Nlom & Karimov, 2015) and the Slutsky substitution (Sasakura, 2016) concepts. Higher-income was significant in explaining the transition from kerosene to LPG as the preferred cooking energy among Lagos urban dwellers (Ozoh et al., 2018). Among other contributions to the preference of LPG (Quinn et al., 2018), increased income facilitated the financing of requisite investment including the initial cost of the gas cylinder, nozzles and the routine LPG refilling. Despite low financial investment compared to the initial cost of the gas cylinder and other implements, gas refilling also requiresa substantial amount of money in relation to other energy sources that allows for purchase in small portions. Households assured of earning a stream of income are more likely to invest in normal and luxury goods. Among the cooking energy that was adopted by households in western Kenya, LPG could be considered as being either a normal or a luxury good. Notwithstanding the fact that in the long term LPG may be cheaper than some of the traditional sources (Ozoh et al., 2018), especially in most instances where governments are involved in its subsidy (Quinn et al., 2018).

Other factors that were not significant but were associated with increasing the likelihood of households' preference of LPG rather than firewood in breakfast preparation included levels of investment in agriculture; the amount of maize produced; adoption of improved cooking stoves and solar panels for lighting; gender of household head; household head level of education; the number of livestock enterprises; and land ownership among others. All these observations could be associated with increased income welfare and the direction of influencing preference of LPG was consistent with the energy ladder concept (Muller & Yan, 2018; Nlom & Karimov, 2015). The current study joins others that have related household transition from conventional solid sources to cleaner non-solid to positive change in income welfare. The observed positive relationship betweenthe duration of firewood gathering outings and preference for LPG could also be argued from the Environmental-Kuznets Curve (EKC) hypothesis (Akther et al., 2010).

The likelihood of a household's preference for twigs than firewood in breakfast preparation was significantly ($P \leq 0.01$) influenced by the number of houses owned, reliance on own farm for firewood collection and the cost of firewood. Membership to farmers' groups, credit access and amount of land owned by the households were weakly significant ($P > 0.1$) in influencing the households' likelihood of preferring twigs in relation to firewood. Considering the probable factors and the direction of preference likelihood for twigs utilisation, it is concluded that the fuel is an inferior energy source. With firewood being used by a large proportion of households and being the base of analysis, the preference of twigs as firewood prices rose testified to the inferiority (Menegaki et al., 2020) of twigs. A poor household may only have one house butas access to income increases the capital to construct more houses becomes a reality. Ownership of larger parcels of land is associated with wealth, which could also be considered as an indicator of positive welfare. Households without networking opportunities provided by the membership to farmers' group showed the likelihood of preferring twigs instead of firewood.

Households concerned with warming house environment when choosing cooking energy; the longer the distance covered to fetch firewood and the per capita expenditure significantly ($P < 0.05$) increased the likelihood for preference of agricultural crop wastes rather than firewood for breakfast preparation.

The significant level ($P < 0.01$), the likelihood of households' preference of transition fuels as a breakfast source of cooking energy was influenced by households members' average education and membership to farmers' groups. Other factors that were observed to influence the likelihood of preference of transition energy sources ($P<0.05$) included the proportion of females in a household and the proportion of food produced. Both firewood and twigs are collected from the farmlands and/or forests mostly by women (Jan & Pervez, 2015), expectations were if the proportion of femalesis reduced, the likelihood of households preference of the transition fuels compared to firewood was increased. The observed inverse relationship between the proportion of females in a household and dependency on firewood is consistent with other studies in Ethiopia and Nigeria concurrently (Alem et al., 2016; Ali et al., 2013).

Factors that were observed to significantly influence the likelihood of preference of more than one energy source concerning firewood for breakfast preparation included households enjoying credit facilities, household dependency on agriculture for livelihood, and per capita consumption expenditure. The likelihood for preference of LPG, transition energy and twigs for breakfast preparation was significantly influenced by credit access.

4.3.3 Determinants of lunch cooking energy choices among smallholders

Table 4.7 shows the Multinomial logit regression results for lunch cooking energy choice and factors influencing the outcomes. The LR chi2 (69), Prob>chi2, Pseudo R^2 and log-likelihood regression outcome was 141.2, 0.00, 0.21.9 and -264.4 respectively. The statistical outcomes of the MNL analysis for lunch were very close to those observed for the breakfast.

The proportion of households utilizing LPG for both lunch and supper reduced, hence the variable for LPG could not be analysed separately. The few instances of usage of LPG among households were lumped together into a 'cleaner energy' variable than the unprocessed biomass sources. The likelihood of households' preference of twigs rather than firewood as a lunch cooking energy source was significantly ($P \leq 0.01$) influenced by reliance on own farm for biomass energy gathering and ability of a household to meet maize demand through own production. Relying heavily on agriculture for livelihood and firewood prices increased the likelihood of households preferring twigs compared to firewood in lunch preparations. The fact that both own farm reliance for biomass and high dependency on agriculture for livelihood were significant in influencing the likelihood of households' preference of twigs as lunch cooking energy source proved the existence of a relationship between energy sourcing, agricultural production and household livelihood status.

Table 4.7 Results of Multinomial Logit regression on determinants of lunch cooking energy choice in western Kenya

	Twigs		Agricultural wastes		Cleaner energy	
Variables	Coefficient	Std.err	Coefficient	Std. Err	Coefficient	Std.err
Log_ Household head age (years)	-0.11	0.89	-0.60	0.75	-0.90	0.75
Sqrt_proportion of female	1.56	1.25	0.41	1.38	-0.29	1.11
Sqrt_duration per outing of firewood (min)	0.01	0.06	-0.01	0.05	0.01	0.05
Sqrt_2017 agricultural investment (KES)	0.00	0.00	0.00	0.00	0.00	0.00
Sqrt_2017 Maize production (kg)	0.01	0.02	0.03	0.01***	0.00	0.01
Sqrt_Weekly firewood cost (KES)	0.08	0.03***	0.00	0.02	-0.04	0.02*
Sqrt_ Distance to firewood gathering	0.85	0.52	-1.08	0.64*	0.10	0.51
Log_ daily per capita expenditure (KES)	0.58	0.46	0.18	0.36	0.03	0.35
Adoption of improved cooking stove	-0.95	0.55*	-0.64	0.46	0.15	0.44
Conscious of warming the house	-0.30	0.60	0.98	0.45**	0.00	0.49
Number of houses in a household	-0.64	0.33	0.01	0.24	-0.12	0.28
Adoption of solar energy	0.53	0.51	0.31	0.44	0.50	0.44
Membership to farmers group	-1.49	0.96	-0.97	0.75	-0.59	0.70
Household enjoying credit facilities	1.39	1.03	0.54	0.72	1.10	0.70
Own food production proportion (%)	-0.03	0.01***	0.01	0.01	-0.01	0.01*
Own farm firewood reliance	2.16	0.62***	0.36	0.50	-0.46	0.49

Members gathering firewood (no)	-0.24	0.27	-0.15	0.22	-0.22	0.29
Household head average formal educ.(years)	-0.10	0.07	-0.03	0.07	-0.03	0.07
household size (no.)	0.09	0.15	0.32	0.13**	-0.07	0.14
Household head gender	0.30	0.65	-0.69	0.52	-0.28	0.52
Household head formal employment	1.79	0.79**	-0.61	0.72	1.22	0.57**
Proportion of adults (%) propadults	0.06	1.22	1.92	1.07*	0.89	1.08
Sqrt_ Land owned (ha)	-0.97	0.62	-0.24	0.37	0.50	0.37
_cons	-4.46	3.99	-3.62	3.32	3.31	3.16
The LR chi2 (69) = 141.25	Pseudo R^2 = 0.219					
Prob>chi2 = 0.00	log likelihood = -264.25					

Households who owned more houses were observed to be less likely to prefer twigs compared to firewood as a lunch preparation fuel.

Factors influencing the likelihood of households preferring agricultural crop waste instead of firewood for lunch preparation included economic welfare presented by per capita expenditure ($P \leq 0.05$) and consciousness of warming the house environment($P \leq 0.01$) when deciding on the choice of cooking energy. A household head who had achieved more years of formal education and households with a larger proportion of adults were more likely to prefer agricultural waste compared to firewood although the influence was weakly significant ($P \leq 0.10$). Factors that significantly influenced the preference for cleaner energy compared to firewood as lunch cooking energy sources were adult equivalent and formal employment. The two factors decreased the likelihood of households' preference of modern cooking energy sources including LPG, charcoal and kerosene. Households with a larger proportion of their members being adults were less likely to prefer modern energy sources compared to firewood.

The cost of firewood and reliance on own farm for wood fuel was observed to positively influence the likelihood of households' preference of twigs compared to firewood for both lunch and breakfast. The number of houses owned by a household negatively influenced the likelihood of households' preference for twigs in relation to firewood in lunch and breakfast preparation.The direction of influence associated with households' proportion of own staple food production on the likelihood of preference for stick in relation to firewood as lunch and breakfast was dissimilar. The consciousness of warming the house environment was positively associated with the likelihood of households' preference of agriculture crop waste in relation to firewood for both lunch and breakfast preparations. Per capita consumption expenditure influenced the likelihood of households' preference on agricultural crop waste compared to firewood in different directions for lunch and breakfast. The directional differences on the likelihood for households' preference for a fuel type by a specific factor were associated with food type prepared, duration required to complete cooking and the composition of the household to enjoy such a meal.

4.3.4 Determinants of supper cooking energy choices among smallholders in western Kenya

Table 4.8 shows the Multinomial logistic regression results for determinants of supper cooking energy choice among households in rural western Kenya. The LR chi2 (69), Prob>chi2, Pseudo R^2 and log-likelihood regression outcome for supper were 161.82, 0.00,

Table 4. 8 Results of a multinomial logit regression on determinants of supper cooking energy choice in western Kenya

Supper	Twigs		Agricultural wastes		Cleaner energy	
Variables	Coefficient	Std.err	Coefficient	Std.Err	Coefficient	Std.err
Log_ Household head age (years)	-0.50	0.93	-0.76	0.78	-1.69	0.94*
Sqrt_proportion of female	1.71	1.28	0.39	1.50	-0.80	1.36
Sqrt_duration per outing of firewood (min)	-0.04	0.07	-0.02	0.06	0.07	0.06
Sqrt_2017 agricultural investment (KES)	0.00	0.01	0.00	0.00	0.00	0.00
Sqrt_2017 Maize production (kg)	0.01	0.02	0.02	0.01*	-0.03	0.02**
Sqrt_Weekly firewood cost (KES)	0.07	0.03**	0.00	0.02	-0.07	0.03**
Sqrt_ Distance to firewood gathering	0.91	0.54*	-1.20	0.66*	0.10	0.55
Log_ daily per capita expenditure (KES)	0.53	0.49	0.45	0.38	0.01	0.38
Adoption of improved cooking stove	-1.35	0.64**	-0.87	0.50*	1.35	0.52***
Conscious of warming the house	-0.03	0.65	1.47	0.47***	0.27	0.54
Number of houses in a household	-0.50	0.35	0.09	0.25	0.14	0.32
Adoption of solar energy	0.07	0.55	0.22	0.46	-0.28	0.51
Membership to farmers group	-1.34	1.09	-0.96	0.79	-0.60	0.86
Household enjoying credit facilities	0.91	1.15	0.25	0.75	-0.47	0.96
Own food production proportion (%)	-0.02	0.01**	0.01	0.01	0.00	0.01
Own farm firewood reliance	1.64	0.64***	0.18	0.52	-1.29	0.57**
Members gathering firewood (no)	-0.14	0.27	-0.11	0.23	-0.92	0.50*

Household head average formal educ.(years)	-0.12	0.08	0.03	0.07	0.04	0.09
household size (no.)	0.07	0.17	0.37	0.13***	0.12	0.17
Household head gender	0.55	0.68	-0.63	0.53	-0.12	0.69
Household head formal employment	1.30	0.95	-1.04	0.77	0.84	0.64
Proportion of adults (%) propadults	0.01	1.30	0.83	1.08	-0.18	1.30
Sqrt_ Land owned (ha)	-0.89	0.72	-0.03	0.36	0.82	0.43*
_cons	-2.36	4.21	-4.15	3.46	4.82	3.75
LR chi2 (69) =161.83	Pseudo R^2 = 0.264					
Prob>chi2 =0.00	log likelihood = -224.71					

0.26.4 and -224.71 respectively. The statistical outcomes of the MNL analysis for supper were very close to those observed for lunch and breakfast.

Reliance on own farm for biomass energy sourcing was significant ($P \leq 0.01$) in influencing the household's likelihood of preference of twigs instead of firewood as a supper cooking energy source. Factors that were significantly weak in influencing the likelihood of households' preference of twigs to firewood in supper preparation included the cost of firewood, the distance of gathering the firewood, amount of land owned and credit access. The likelihood of households' preference of agricultural waste rather than firewood for supper preparations was influenced by the consciousness to warm house environment as they selected cooking energy ($P <0.01$), distance to fetch firewood and per capita expenditure ($P< 0.05$). The likelihood of a household preference of transition energy rather than firewood was significantly ($P< 0.01$) influenced by the membership to groups and households' average education levels. The proportion of females, credit access and ability of a household to meet food demands through own production significantly ($P < 0.05$) influenced the likelihood of a household preference of the transition energy sources.

4.3.5 Marginal effects of choice of cooking energy for various meals preparations in western Kenya

Results of average marginal effects for firewood and its probabilities of use for various meals are shown in Table 4.9. Households were observed to have 90%, 92% and 97% probabilities of choosing firewood as the energy source for cooking breakfast, lunch and supper respectively. The probability of adopting modern energy (LPG) was only 0.3% for breakfast which was quite low although notable considering the extremely low expectation for its likelihood of being preferred for the preparation of other key meal types.

Table 4. 9 Marginal effects on determinants of cooking energy choice for various meals.

Variables	Breakfast energy choice		Lunch energy choice		Supper energy choice	
Probability for energy choice for various essential meals	Pr (LPG_gas = 4%) Firewood = 74%		Pr (Firewood =78%)		Pr (Firewood= 86%)	
Marginal effects	dy/dx	Std. Err	dy/dx	Std. Err.	dy/dx	Std. Err.
Log_ Household head age (years)	0.014	0.011	0.108	0.086	0.112	0.067*
Sqrt_proportion of female	0.006	0.011	-0.057	0.139	0.049	0.112
Sqrt_duration per outing of firewood (min)	0.000	0.000	-0.001	0.006	0.000	0.005
Sqrt_2017 agricultural investment (KES)	0.000	0.000	0.000	0.000	0.000	0.000
Sqrt_2017 Maize production (kg)	0.000	0.000	-0.003	0.001*	0.000	0.001
Sqrt_Weekly firewood cost (KES)	0.000	0.000	0.000	0.003	0.000	0.002
Sqrt_ Distance to firewood gathering	-0.005	0.005	0.036	0.062	0.043	0.048
Log_ daily per capita expenditure (KES)	0.007	0.006	-0.029	0.040	-0.043	0.032
Adoption of improved cooking stove	0.008	0.007	0.059	0.051	0.039	0.044
Conscious of warming the house	-0.003	0.003	-0.073	0.064	-0.135	0.061**
Number of houses in a household	-0.001	0.002	0.028	0.030	0.005	0.022
Adoption of solar energy	0.003	0.004	-0.073	0.050	-0.007	0.038
Membership to farmers group	0.032	0.030	0.133	0.067**	0.097	0.049**
Household enjoying credit facilities	-0.014	0.011	-0.187	0.109*	-0.037	0.081
Own food production proportion (%)	0.000	0.000	0.001	0.001	0.000	0.001

Own farm firewood reliance	-0.002	0.004	-0.057	0.058	-0.012	0.048
Members gathering firewood (no)	-0.004	0.004	0.033	0.029	0.039	0.022*
Household head average formal educ.(years)	0.000	0.001	0.008	0.008	0.000	0.006
household size (no.)	-0.002	0.002	-0.019	0.016	-0.028	0.012**
Household head gender	0.006	0.005	0.064	0.068	0.035	0.054
Household head formal employment	0.027	0.025	-0.191	0.104*	-0.053	0.083
Proportion of adults (%) propadults	-0.025	0.020	-0.191	0.123	-0.045	0.091
Sqrt_ Land owned (ha)	0.003	0.003	0.011	0.045	0.003	0.036

4.4 Conclusion

Several conclusions were derived from this study on cooking energy revealed preference among smallholders involved in maize farming in western Kenya. Consistent with other studies across sub-Saharan Africa, biomass especially firewood was the most preferred cooking energy source in the sampled area. The higher level of reliance of households on firewood compared to other cooking energy reported in this study in relation to others was however attributed to the sampled area being rural. Twigs were observed to be inferior cooking energy sources as the likelihood of their preference compared with firewood was influenced by the latter's price and the decrease in households' disposable income as was presented by the per capita consumption expenditure. Desegregation of cooking energy utilisation by the key meals types including breakfast, lunch and supper has revealed insights on the household choice decisions. Each of the three key meals prepared by the households could be evaluated separately for the determinants of cooking energy choice and the levels of utilisation of each of the cooking energy options. The likelihood of households' adoption of clean energy sources was linked more with breakfast preparation than all the other meals, followed by supper and lastly lunch. Strategies targeting transition to clean energy, especially LPG are expected to be more successful if more efforts are directed to breakfast meal preparation and issues associated with it.

The concept of energy stacking has remained majorly unexplained (Quinn et al., 2018) and through disaggregating energy sources and by meals more insights have been provided. A relatively larger proportion of households preferred the LPG for breakfast preparation but continue stacking other forms of energy sources for the sole aim of using them for supper or/and lunch preparation. The use of agricultural waste, mostly maize cobs were associated with cooking during cold seasons or supper when the households were also yearning to warm the residence. Energy stacking is also a factor of seasonality; the use of agricultural/maize wastes corresponds to the duration of crop harvesting and immediately after. Later, duration of use of high reliance on firewood, twigs and other sources are also experienced subject to the time of the year and rainfall patterns. The study affirms the challenge of rural households failure to climb the energy ladder but instead illuminates the preference of the energy stacking. The conclusion is akin to that of another study in rural Pakistan on evidence of energy stacking (Jan et al., 2012).

Nevertheless, consistency was observed on the significant factors and the direction of influence affecting choices for cooking energy used for various meal types. Across all meal types, reliance on own farm for firewood significantly influenced the likelihood of households' preference of twigs compared to firewood. The preference of agricultural crop waste in relation to firewood as a cooking energy source was influenced across meal types by the desire for warming houses.

Despite western Kenya having sub-counties clusters showing salient contrast in agro-ecological, socio-economic and energy access environments no significant differences were observed on determinants of cooking energy choice between the clusters. The region's sub-county farming community could therefore be considered as homogenous on cooking energy sourcing and determinants of optional fuel used. However, significant differences in the choice of cooking energy were observed as influenced by welfare characteristics including formal employment, reliance on own farm for biomass energy, average pool of household years of education, per capita income, credit and proportion of females and adults in the household. Agricultural production factors influencing the choice of cooking energy included the levels of maize production and the proportion of food covered by household own production. The cost of firewood and the distance covered to fetch firewood were fuel sourcing factors influencing the choice of energy.

This study's outcome has also been able to confirm various concepts associated with the choice of cooking energy including the transition ladder (Muller & Yan, 2018), the energy stacking (Muller & Yan, 2018) and the environment-Kuznets (D´emurger & Fournier, 2011). The incorporation of agricultural production variables has attested to the existence of a relationship between energy choice and agricultural production as explained through the agricultural households' models.

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CHAPTER FIVE

EFFECT OF BIOMASS FUEL USE AND DEMAND ON AGRICULTURAL PRODUCTION AMONG HOUSEHOLDS IN WESTERN KENYA

Abstract

Households' effort to meet cooking energy demand has reduced the smallholders' available resources for agriculture including land, labour and capital. Research gaps on the relationship between the demand for cooking energy and food production prevail. Using a database from a smallholders' survey of 400 respondents in western Kenya, a three-stage least square (3SLS) model was run to determine the effect of biomass cooking energy usage and demand on food production; to establish the presence of trade-off or synergies between biomass cooking energy sourcing and agricultural production, and to evaluate the key socio-economic factors simultaneously affecting agricultural production and biomass cooking energy sourcing. Labour abundance was observed with less than a third allocated to productive activities including agriculture, biomass energy sourcing and off-farm employment. Analysis outcomes showed maize yields to be significantly influenced by age of household head, the number of trees managed, agricultural labour allocated and DAP fertiliser application levels. Labour allocation to agriculture was significantly ($P \leq 0.05$) influenced by labour allocated to biomass gathering, the number of individuals in a household and the proportion of adults. Capital allocation to agriculture by households was significantly ($P \leq 0.05$) influenced by other non-agriculture and non-energy expenses, and the area allocated to maize. Determinants of land allocation to agriculture included the number of tropical livestock units and the sub-county factors. Synergies were observed between the number of trees managed and the yield of maize achieved, and the labour allocated to agriculture and that allocated to biomass fuels gathering. High spending on cooking energy had negative effects on the amount invested in agriculture. Although the allocation of more land to maize increased the achievement of food sufficiency in the household, it led to decreased number of trees managed.

5.1 Introduction

In most developing countries where smallholders contribute a significant proportion of the total national population, agricultural production resources limitation has remained a major constraint to social transformation (Gatzweiler & von Braun, 2016). With most studies addressing agricultural production development silent on biomass energy utilisation, the incorporation of energy demand associated requirements including allocation of land, capital and labour will worsen challenges linked with smallholding farming. With households facing challenges associated with resources limitation, a situation that has compelled them to a smallholding farming system (Bryceson, 2019), it would be important to understand how pressure associated with cooking energy sourcing could impact subsistence agricultural production. Despite the recent impetus and improved methodologies of understanding the relationship between biomass energy effects on agriculture (Klapwijk et al., 2014), most of the studies are limited to the household competing needs of using agricultural waste as a cooking energy source or soil fertility replenishment (Klapwijk et al., 2014; Tittonell et al., 2015) and feeding livestock or soil fertility augumenation (Koudrim & Hilali, 2020).

The effect of biomass fuel utilisation and demand on agricultural production among smallholders is a complex analysis that could be well understood by the evaluation of production resources trade-off between food and energy. However, it could be absolutely important to evaluate whether smallholders' decisions and behaviours in food production and biomass energy depict synergies. Both sourcing for food and energy are basic needs for the households since foodstuffs have to be cooked using energy for humanity to benefits nutritiously. While cases of resources trade-offs in accessing each of these services may be depicted, the needs are highly interlinked. Synergies in food (agriculture) and biomass energy production has been shown where smallholders have been reported to use crops' waste (Tucho & Nonhebel, 2015) and cowdung either in its raw form (Gupta et al., 2016) or after processing (Gupta et al., 2016; Shaibur et al., 2021) as cooking energy. The adoption of the appropriate agricultural technologies for many crops was reported to have a high potential for agricultural waste usage to replace forest biomass harvesting in Kenya (Kimutai et al., 2014).

Elucidating the relationship between cooking energy sourcing and food production is critical in a number of ways especially in an environment where biomass is the main cooking fuel. First, there is a relationship between food production and biomass energy sourcing on households' economic and social welfare necessitating an intergrated approach (Shupler et al., 2021). Secondly, households' decisions to influence the availability of biomass energy may affect food access as they both, directly and indirectly, depend on similar factors of production including land, labour and limited financial outlay obtainable by the smallholding farming system actors. Thirdly, due to the fore mentioned connections between food availability and biomass energy gathering there may be a two-way relationship between these two elements of basic needs whose determination could be critical for intervention for both agricultural production enhancement and improving cooking energy welfare. Fourth, trees propagation in response to household biomass needs and bio-energy production could ultimately constitute a cash crop thereby depending on the enterprise's characteristics may affect the economic welfare of farmers through an increase in disposable income and capability to rely on purchased food rather than own production.

Finally, the successful intervention for the smallholders on these two social elements directly addresses three of the seventeen United Nations sustainable development goals (Morton et al., 2017) including the goal on no poverty (SDG 1), zero hunger (SDG 2) and affordable and clean energy (SDG 7). However, successful intervention on the three SDGs has a direct bearing on all other resources-restricted production associated goals including good health and wellbeing (SDG 3); quality education (SDG 4); gender equality (SDG 5); clean water and sanitation (SDG 6); decent work and economic growth (SDG 8); reduced inequalities (SDG 10); climate action (SDG 13); life below water (SDG 14); and life on land (SDG 15).

In this chapter evaluation of the effect of biomass fuel use and demand on agricultural production among smallholders was done. Specific objectives addressed included i) to determine the effect of biomass cooking energy usage and demand on maize production; ii) to establish the presence of trade-off or synergies between biomass cooking energy sourcing and agricultural production, and iii) to evaluate the key socio-economic factors simultaneously affecting agricultural production and biomass cooking energy sourcing. The chapter outcomes are critical for policy formulation intervention affecting both agricultural and energy development; designing of extension dissemination messaging and implementation, and addressing the negative effects of production and consumption associated with agriculture and energy.

5.2 Methodology

5.2.1 Data sources.

Data to respond to the objectives of the study was derived from primary sources. The research design adopted was a survey on smallholders involved in maize production.

A survey of smallholders

A survey, as described in Chapter 3 was undertaken. The pre-set open and closed-ended questionnaire had modules that included questions on households' socio-economic characteristics, agricultural and energy production and consumptions, and resources allocations including on labour, finances and land. The socio-economic information collected was associated with the household head and the household. The resources' allocation module was concerned with total labour and its allocation to various productive and reproductive chores. Financial allocations to various household budget lines including energy, agricultural production and other routine costs were also queried. Questions on land allocation to various options including maize production, other agricultural enterprises and trees management were also included in the survey.

Agricultural production modules had questions related to maize production, livestock husbandry and other crops enterprises. Key information on maize collected included the acreage, production levels and yields achieved, and the levels of organic and inorganic fertiliser applications. Many trees surviving after propagation was the other agricultural production information gathered from the households. Energy production and consumption data collected comprised of the cooking, house-warming and lighting energy sources; and quantity gathered, and used.

5.2.2 Data Analysis

A comprehensive review of how biomass energy accessing affects agricultural activities associated with food production in a household entails an analysis of a system of simultaneous equations describing these two elements of basic needs. Through statistical methods for systems of simultaneous equations, the mutual dependence among the variables in the model was to be captured. In this regard, adoptions of techniques allowing for full information disclosure where all equations were estimated concurrently was recommended. Incorporation of all available information in the simultaneous analysis allowed for more efficient parameter estimation. A Three Stages-Least-Squares (Zellner & Theil, 1962) model was adopted to depict the relationship between activities associated with food production and biomass energy sourcing. Simultaneity in the adopted model arose due to some endogenous variables appearing as explanatory (exogenous) variables in other equations thereby imposing the dynamic structure in undertaking the analysis (Zellner & Thornber, 1966)

The three-stage least-squares method generalizes the two-stage least-squares method to take account of the correlations between equations. Three-stage least squares require three steps (Jorgenson & Laffont, 1975) including first-stage regressions to get predicted values for the endogenous regressors; a two-stage least-squares step to get residuals to estimate the cross-equation correlation matrix; and the final third stage least square estimation step. Three-stage least squares estimates are consistent and asymptotically normal, and in some conditions, asymptotically more efficient than single equation estimates.

Empirical estimation for a system of structural equations for agricultural productivity and efforts for availing biomass energy was specified to establish co-efficiencies. Assumptions made on the error term of structural equations determined the choice of the estimator for the system of equations. Having some right-hand-side variables that were under the choice set of the household, it was assumed that the error terms were correlated with some explanatory variables. Since households made simultaneous decisions on agricultural production and biomass accessing efforts, it was assumed that the error terms were correlated across equations. The three-stage least squares (3SLS) estimator was adopted with instrumental variables for right-hand endogenous variables while paying attention to the covariances across equation disturbances to improve the precision of the estimates. The 3SLS model is generally presented as in Equation 5.1.

$$y_u = Y_u \gamma_u + X_\mu \beta_\mu + u_\mu = Z_\mu \delta_\mu + u_\mu \tag{5.1}$$

where yμ, is the column vector of observations on one of the joint variables occurring in that equation; Yμ is the T x mμ, matrix of values taken by explanatory dependent variables of that equation; yμ, is the corresponding coefficient vector; Xμ is the T x 1, matrix of values taken by the explanatory predetermined variables; βμ is its coefficient vector; uμ is the column vector of T structural disturbances as presented in Equation 5.2

$$Zu = \begin{bmatrix} Yu & Xu \end{bmatrix} \quad \delta u = \begin{bmatrix} \frac{Yu}{\beta u} \end{bmatrix} \tag{5.2}$$

The empirical structural equations used in evaluating the effects of biomass energy on food (maize) production were as presented in Equations 5.3 to 5.7

$$Y = \alpha + \beta_1 Z_H + \beta_A A - \beta_E E - \beta_{OF} \mathrm{OF} + \mu \tag{5.3}$$

$$H_R = A_R + E_R + \mathrm{OF_R} \tag{5.4}$$

$$A_R = \alpha_A + \beta_1 Z_A - \beta_E E_R - \beta_{OF} OF_R + \mu_A \qquad (5.5$$

$$E_R = \alpha_E + \beta_1 Z_E - \beta_A A_R - \beta_{OF} OF_R + \mu_E \qquad (5.6)$$

$$OF_R = \alpha_{OF} + \beta_1 Z_{OF} - \beta_A A_R - \beta_E E_R + \mu_{OF} \qquad (5.7)$$

Whereas Y is an endogenous variable representing a desired agricultural outcome including maize yield or productivity and sufficiency in food through own production. α is a constant for each of the structural equations. β_1 is a coefficient associated with a matrix of socio-economic factors of household increasing decision making. Z_H represent a matrix of socio-economic characteristics that influence household decision making. For the case of labour, A, E and OF represent households' agricultural, energy sourcing and off-farm employment respectively. While in the case of capital, OF may represent expenses associated with others with exception of those related to agriculture and energy. B_A, β_E and β_{OF} represent the co-efficiency for agricultural, energy sourcing and off-farm/other expenses respectively. μ is an error term.

The total household resources (H_R) are allocated towards agricultural production (A_R), energy sourcing (E_R) and off-farm engagement/ other expenses (OF_R). The household resources evaluated separately include labour, capital and land. In the case of labour, the amount considered in the analysis was that quantity allocated to productive activities i.e. agriculture, energy sourcing and off-farm employment. The amount used in other activities including leisure was considered non-productive. The amount of household land allocated to off-farm activities or other non-agricultural or non-tree planting uses was considered to be negligible and tending towards zero.

The empirical execution of the model on labour allocation led to several assumptions being made; key among them the market failure for household labour. The labour market failure assumption was consistent with the postulation of the separability hypothesis test studies in developing countries (Chan, 2019). With labour allocation to leisure accounting for 80%, a low or absence of formal labour engagement (at 13%) by households concurs with the non-separability model (Le, 2010). Market failure was also affirmed by labour payment in kind by meals provision or the take-home ration of staple (McCullough, 2017). Moreover, the practised rain-fed agricultural production systems develop short instances of high labour demand that is dependent on household characteristics (Le, 2010).

5.3 Results and Discussion

5.3.1 Household socio-economic characteristics and effects of biomass energy on agricultural food production.

Table 5.1 shows households' demographic factors postulated to have implications on the effects of biomass fuel use and demand on food production in western Kenya. The

Table 5. 1 Socio-economic characteristics of households in western Kenya

Variable	Mean	Std. Dev.	Min	Max
Gender_Male headed households	0.78	0.42	0	1
Household head age (years	49.65	15.53	20	93
Experience farming (years)	20.84	15.12	1	75
Formal employment (%)	0.13	0.34	0	1
Households' members mean age(years)	25.87	12.79	7.6	79
Household size	5.35	2.13	1	13
Adults time in hours per year (2017)	15223.63	7232.86	4368	48630.4
Total household duration in 2017 (hours)	19727.68	8576.25	4680	58780.8
Households' schooling duration in 2017 (hrs)	2159.04	2292.45	0	8160
Household's leisure duration in 2017 (hrs)	12968.43	6943.40	832	40176
Ratio of Leisure to total households time (%)	79.6	18.2	19.6	99.8
Firewood fetching duration in 2017(hrs)	249.2	390.3	0	4368
Farm working (hours)	3125	2245.1	156	13104
Off-farm working (hours)	1325.2	1895.1	0	10608
Adults proportion (%)	0.58	0.25	0.09	1
Female proportion (%)	0.43	0.20	0	1
Household average education (years)	8.18	3.05	1	17.83
Household head education (years)	9.54	3.78	1	16
Credit access (%)	0.23	0.42	0	1
Per adult equivalent annual expenditure	24293.7	16178.04	3755.14	98648.65

demographic factors highlighted were associated with general household characteristics in terms of decision making as presented by gender of household head and years of formal education; the age of the household head and durations of experience in smallholding farming. Other factors critical in influencing energy use decision making in a household included the household head being formally employed and average years of formal education of household members (Rahut et al., 2016) as they positively influence taste and class resulting in less use of biomass energy. The number of members in a household, the proportion of adults and that of females increases the labour availability and hence allocations for both agriculture and energy sources. In traditional African communities, biomass energy sourcing was considered a reproduction household function and hence mostly performed by female members.

Household heads and the average household members' years of formal education reported could be deemed as a positive achievement considering that it was above those of primary education (Milligan, 2017). With such years of formal education, households were expected to make informed decisions on the allocation of production resources to either food production or energy. Household head and the households' stock of education has been considered as playing important role in enhancing human capital and hence resultant investment and production decisions (Reimers & Klasen, 2013). At an average of 50 years, household heads in the research area were quite advanced in age considering the life expectancy in Kenya of 68.9 years (WHO, 2020). The older households' heads would be reluctant to adopt both the high yielding agricultural technologies and modern cooking energy technologies. In this regard, by old household heads using traditional technologies, low yields will be reported and hence the effect of production resources diversion to biomass energy sourcing may be more detrimental to food security.

The relationship between household age and their reluctance to adopt agricultural technologies among smallholders has been described (Djibo & Maman, 2019). Household access to income as reflected by consumption expenditure is another important factor in determining investments in agriculture and energy. Households with more disposable income and hence reported high consumption expenditure may not have the allocation of their resources to food production restricted by those used in energy. However in the case of the poor, competing household requirements including medical and education will highly constrain investment in agriculture production and cleaner energy (Russell, 1996).

Labour access demographic factors were critical in influencing both agricultural production and biomass cooking energy sourcing and gathering. Key labour associated demographic factors described included the total time available for allocation by the households and, labour time associated with adults and that for those going to school. It was however observed that the largest proportion of time resources (80%) was allocated to leisure. The time allocated to leisure may indicate the availability of excess time and/or household preference to engaging in non-productive activities. The small sizes of the farms and the seasonality of agricultural production activities as influenced by patterns of rainfall affected labour allocations. Households may be having peaks of labour demand for agricultural production and durations of low on-farm activities. Options of labour allocations to other productive activities beyond agriculture including off-farm employment and biomass energy gathering were also allocated a low proportion of time in relation to total available.

On average agricultural production, firewood fetching and off-farm time allocations accounted for 21%, 2% and 9% respectively of the time available for adults' household members. Of the total household available duration in a year, the time associated with adults household members accounted for about 77%. The low proportion of utilisation of the available labour to productive activities could also be associated with high dependency among family members due to limited access to both formal employment and opportunities to indulge in off-farm employment (Nolte & Ostermeir, 2017). While formal employment is influenced by the country's duration of sustainable economic growth attributable to the appropriateness and implementation of macro and micro-economic policies, the local economic environment also plays a critical role in impacting off-farm employment. In an agricultural neighbourhood, the success of the farming enterprise in providing decent livelihood and income will spur off-farm employment opportunities with the latter enhancing the agricultural sector (Giannakis et al., 2018). The role of rural off-farm employment to spur rural economic development including agriculture (Wang et al., 2017) therefore safeguarding rural residents from falling into poverty but also reducing the incidence of poverty has been reported (Li et al., 2021).

In western Kenya, it was observed that both the agricultural sector and off-farm employment failed to perform economic well to attract smallholders and their families to allocate labour in them. Moreover, the two failed to provide sufficient disposable income to spur allocations of more time on biomass cooking energy. In economics, allocation of labour or any other resources to any productive activity is associated with a household valuing such activity as having reached a reserve price hence getting attracted (Noltea & Ostermeir, 2017). High allocation of time to leisure (80%) implies that engagement in other activities had low reserve prices. Household reserve price is influenced by farm production technology, output and input prices (Picazo-Tadeo & Reig-Martinez, 2005).

Labour allocation to agricultural and energy production has been reported to be influenced by its availability, competing options (Chen & Mirzabaev, 2016) and the characteristics of a household (van den Broeck & Kilic, 2017). However, what was being observed was a scenario where a higher proportion of labour was dedicated to leisure raising concerns on its competitiveness in allocations, its price and the viability and the effectiveness of adopting the agricultural households' models for analysis. Agricultural households' models are viable for analysis of households in case of non-separability in decisions for production and consumption common in imperfect markets for resources (Le, 2010) including labour. The labour allocations' proportions observed implied that the resource was not competitive in its allocation and the market was therefore imperfect.

5.3.2 Households' Agricultural production characteristics and effects of biomass energy on food production

In addressing the effects of biomass energy sources on agricultural production among smallholders, it was essential to consider the agricultural production factors for several reasons. First, the agricultural production factors would be candidates for change when demand for biomass energy introduces pressure on agriculture production. Competition for labour, land and capital arising from the demand for biomass cooking energy will have effects on agricultural production as the sector relies on the same resources for its operations. With competition, smallholders may have to reduce or do away with resources utilised in agricultural production and instead allocate the foregone inputs to cater for the demands associated with cooking energy. In case of biomass cooking energy demand leading to higher cost and the household having limited financial resources, it will be forced to reduce the finances utilised on agriculture including the hiring of labour and amount of fertiliser used among others.

In some instances, the agricultural production factors were similar to those associated with biomass energy gathering. Moreover, some of these agricultural factors will influence the shift to cleaner energy thereby reducing the pressure on biomass energy demand. Agricultural production characteristics that enhance productivity and hence income could have a twin effect of stimulating higher agricultural returns and adoption of cleaner energy in compliance to the energy ladder theory. The energy ladder hypothesis stipulates that as the household income increases households shift progressively from traditional to modern sources of cooking energy (Kroon et al., 2013).

Table 5.2 shows the agricultural production factors that were anticipated to be impacted by the increased biomass cooking energy demand and hence the overall agricultural production. Households' agricultural diversification strategies were observed for both crops

Table 5. 2 Households' agricultural production characteristics

Variable	Mean	Std. Dev.	Min	Max
Membership to farmers' groups	0.25	0.43	0	1
Number of livestock enterprise	1.89	0.87	0	3
Tropical livestock units(TLU)	1.879	1.	0	15.4
Owning Title deed to farm (%)	0.55	0.49	0	1
Annual Rainfall (mm)	1559.93	262.31	1275	1900
Altitude (m.asl)	1821.84	420.14	1300	2475
Size of land owned (ha)	2.43	3.17	0.13	20
Maize area (ha)	0.68	2.27	0.04	40.69
Number of crops enterprise farmed	2.54	0.84	1	5
DAP applications in 2017 ($kgha^{-1}$)	217.41	387.99	0	5335.
CAN applications in 2017 ($kgha^{-1}$)	191.64	234.66	0	2519.
Manure applications in 2017 ($kgha^{-1}$)	310.90	1410.2	0	19760
Type of fertiliser used (Number)	1.97	0.743	0	3
Maize yield in 2017 ($kgha^{-1}$)	3299.77	4013.51	49.4	31122
Average maize production (kg)	1596.26	3074.36	10	40500
Average number of trees	127.72	259.29	0	2000

and livestock enterprises. Livestock diversification strategies were depicted by the tropical livestock unit (TLU) and the number of livestock enterprises adopted. Appendix C3 shows how TLU were calculated (Ostrow et al., 2020). While on average the adopted two livestock enterprises were high, the values of the tropical livestock units were low. This observation on the TLU implied that even the scales of livestock husbandly were low despite the potential of intensification even in small land units (Mosites et al., 2015; Msangi et al., 2014). The average of 2.5 more crops' enterprises beyond maize which included beans, tea, coffee, tobacco, banana, Irish potatoes, sweet potatoes, groundnuts and cassava could be considered a positive agricultural strategy; however, the small landholding for each of the enterprises was a disincentive for growth on sustainable agriculture that could assure livelihood and increased incomes. Diversification to multiple crops observed was a common smallholding phenomenon (Mango et al., 2018; Meena et al., 2018) which was attributed to the desire for risk averseness in case of one enterprise failing, enhancing income and food security and efforts of maximizing the utilisation of agricultural production resources (Paudel, 2016).

On average the 0.6 ha allocated to maize production, and 1.8 ha dedicated for homestead, the other crops' enterprises and livestock enterprise depicts a system that is under distress in land allocation. Any pressure associated with biomass energy sourcing would worsen the situation. The higher standard deviations reported on TLU, total land owned and that which was allocated to maize depicted low resources ownership and investment portfolio. A quarter of the households' heads sampled were members of farmers' groups, implying that they stood to benefit from information dissemination and hence could enhance agricultural productivity and adopt better agricultural technologies (Mwaura, 2014). The farmers' group platform could also play a critical role in enhancing cooking energy shifts to cleaner energy thereby reducing pressure from biomass resources' utilisations. It is nevertheless important to note that even in cases where households adopt clean energy sources, financial resources to purchase the cylinder, burners and the routine filling-in of the liquefied petroleum gas (LPG) would be necessary.

The average levels of fertiliser utilisation were high with on average households adopting two fertiliser types on maize production. The rates of fertiliser applications were considered as high comparing the outcome of other studies that reported lower rates of applications (Misiko et al., 2018). However, concerns on the observed fertiliser utilisation patterns in the sampled area included the high standard deviations and the fact that some farmers didn't apply some or any soil fertility replenishing input. With small landholding owned, the optimal application of fertiliser accounted for a production intensification method that could assure increased yields. The increased yield would not only depict higher returns per unit of land, but also other resources including labour, capital and agro-ecological factors. Higher returns in agricultural production allowed for the saved resources arising from efficient utilisation to be released for other production activities including biomass energy sourcing or shift to cleaner energy sources. Moreover, increased yields would guarantee better incomes especially when surplus for sale were available and the product price favourable.

The outcome of the yields showed wide differences among smallholders in returns for investment in maize production per unit area. The diversity implied that while some farmers might have required large areas of land to meet their food demand, others needed relatively smaller land sizes. Farmers reporting low yields required more land to meet their food demand and increase financial returns from maize farming. The larger land areas required would have necessitated even more resources for ploughing, weeding, seeds, fertiliser and rent for the land. The increased resources' requirement for households reporting low yield meant that they would be under pressure to meet biomass energy demand. Moreover, those recording low yield might not have met their food requirement and incomes associated with surplus production.

On average the yield outcomes reported in this study was 3.3tha^{-1} which represented a yield gap of 45% based on research recommendations (Munialo et al., 2019) for maize in Kenya. However, this yield was higher than that reported to be expected by farmers in western Kenya even during good seasons of 2.3tha^{-1} (Woomer & Mukhwana, 2004). Nevertheless, it was lower than those reported in the 90th percentile of farms in two sites in Kakamega and Vihiga counties of 5.1tha^{-1} and 4.8tha^{-1}, respectively (Munialo et al., 2019). Wide yields differences were observed on the yield reported by households in western Kenya similar to those reported by other studies (Munialo et al., 2019; Woomer & Mukhwana, 2004). The yields' variations were associated with the edaphic and climatic factors for the locations and the differences in socio-economic characteristics of the smallholders. The edaphic and climatic factors influence the potential of soil in retaining soil moisture.

The observed adoption of tree farming could be considered as well developed based on the average land owned, number of other crop enterprises and the number of individuals per household. With an average of 127 trees per household it implied that, on average every household member was associated with 24 trees and a hectare of land owned had 53 trees. Tree planting despite competing for land with agricultural production could supplement smallholders' income and assure sources of firewood. In this case, there would be a trade-off on land for food production but synergies on increasing income and labour-saving for firewood gathering.

5.3.3 Households cooking energy characteristics and effects of biomass energy on food production

Table 5.3 shows the energy characteristics of the sampled households. Energy utilisation behaviours by a household will determine the expected outcomes on resources' allocations to agricultural production especially where trade-offs will be experienced. Variables associated with household, energy utilisation included installation of solar panel to harness energy from the sun; concerns by a household to heat or warm the house environment as they selected cooking energy source; adoption of improved energy-saving cooking stoves; entirely reliance on the household farm for biomass energy collection. Consideration for warming the house

Table 5. 3 Household's energy characteristics of smallholders in western Kenya in 2017

Variable	Mean	Std. Dev.	Min	Max
Solar adoption (%)	0.52	0.50	0	1
Number of houses in a household	1.95	0.89	1	6
Conscious of warming house (%)	0.21	0.41	0	1
Improved cooking stoves (%)	0.42	0.49	0	1
Daily cooking time durations (hours)	3.05	1.63	0.5	9.25
Average firewood distance km)	0.55	1.06	0	12
A firewood outing duration (minutes)	79.21	82.39	0	480
Own farm firewood gathering (%)	0.58	0.49	0	1
Number of non-firewood cooking sources	1.31	0.91	0	4
Firewood fetching HH members	1.35	0.96	0	6
Annual dependency on firewood (%)	66.64	28.51	0	100
Annual firewood gathering duration (min)	269.78	398.81	0	4368
Weekly expenditure firewood (KShs)	419.64	293.03	0	1400

environment as they contemplated on cooking energy choice implied that a household will adopt biomass cooking sources. The biomass cooking energy will ensure heating of the house environment will be simultaneously achieved as cooking will be taking place. Since heating the house environment is also a specific utility by a household, there was a higher probability of the action being undertaken separately from cooking. More biomass energy will be demanded for house environment heating and cooking, compared with situations where households only require cooking energy. Moreover, adoption of other cooking energy sources may be highly restricted since only biomass energy sources can offer the dual purpose of heating and cooking.

Adoption of solar panels and energy-saving cooking stoves reported by 52% and 42% respectively was deemed as a positive outcome considering that efforts to sensitize households on these two issues have not been acknowledged in the region. Adoption of energy-saving cooking stoves leads to enhanced efficiency in biomass energy sources utilisation thereby reducing on the amount demanded. Reduction in the amount of biomass energy demanded implied low pressure on the production resources subsequently lessening effects on agriculture. The most households were observed to solely depend on their farm for sourcing biomass energy, a positive outcome since labour and capital resources that could be diverted from food production were not necessary.

The high number of houses owned by a household was expected to raise the amount of firewood demanded and hence effort in the biomass collection, especially if they need to heat the residences was required. In rural settings, demand for biomass energy and its ease of access is critical in determining the efforts required in availing it (Hertberg et al., 2000; Okwii & Muhumuza, 2012) and the decision for tree planting and management (Jarneck & Olsson, 2013).

A number of other sources of cooking energy carriers adopted apart from firewood ranged between zero to six. Among the other firewood supplementing sources adopted included electricity, charcoal, LPG, kerosene, sawdust, agricultural crop wastes and livestock dung. Adoption of a rich mix of energy options was expected to substitute firewood in case of suppressed resources especially labour for its collection (Chen & Mirzabaev, 2016). Utilisation and dependence on firewood as a cooking energy source among households was quite high at an average of 67%.

5.3.4 Determinants of maize productivity and allocation of labour to various households' activities

Table 5.4 shows the outcome of a 3SLS analysis on the determinants of maize productivity and those associated with labour allocations to various key activities. In this simultaneous model, the four endogenous variables were maize yields and labour allocation to agricultural production, biomass energy (firewood) collection and off-farm employment. Among the exogenous variables associated with maize yields included labour allocations to agriculture, firewood collection and off-farm employment. Each of the labour allocations to a key activity was an exogenous variable for the other activities. The model specification showed significance (P≤0.01) for each of the four structural equations. The R-squared for agricultural productivity, agricultural labour allocation, firewood collection labour allocation and off-farm employment allocation were 8%, -15.8%, 17.3% and 34.6%, respectively. The negative R-square is not unusual in the case of the 3SLS analysis, and it's an indication that the structural model predicts the dependent variable worse than a constant-only model (Theila, 1971).

Yields of maize were significant (P< 0.05) and positively associated with the number of the trees being managed by smallholders. With the two outcomes of yields and tree planting adoption being the desired consequence to cater for food security, enhanced income, energy security, improved soil agro-ecology and mitigation of climate change effects (Mbow et al., 2014), some farmers have achieved these key economic sustainable goals concurrently. The observation on synergies between maize yield and the number of trees managed could be attributed to the fact that agroforestry has been promoted as an agricultural technology hence in an effort of smallholders to achieve high yield they adopted tree growing. Some farmers could have also resolved to ensure enhanced food and energy security, thereby investing in both technologies for maize yield and maximizing tree growing. Efficient farmers in annual crop (maize growing) might have also wished to diversify to perennial crops, thereby expanding on tree growing.

Maize yield was observed to be significantly (P<0.05) and negatively associated with the amount of labour reported to have been allocated to agricultural production, While this observation was unexpected considering that labour is a key input in agricultural production, the outcome could be associated with the inefficiency in labour utilisation. Inefficiency in the labour allocation argument could be supported by the fact that total labour available was proportionately high than that which was utilised. It was also possible that due to the seasonality of agricultural production, there were peaks and lows in labour demands. The fact that the amount of labour required across the maize production cycle was not constant implied that there were durations of shortage and surplus. These shifting labour requirements in different durations led to inefficiencies in allocations leading to failures in optimal resource utilisation (Sheng et al., 2019).

The amount of labour allocated to firewood gathering and off-farm employment showed an inverse relationship with maize yield; however, the relationship was not significant. All variables associated with labour allocations including agricultural production, off-farm

Table 5.4 Results of a 3SLS analysis on factors influencing agricultural productivity and labour allocations among smallholder

Variables	Maize yields (kgha-1)	Agriculture labour (hours per year)	Firewood labour (hours per year)	Off-farm labour (hours per year)
exogenous variables	Coef. (Std. dev)	Coef. (Std. dev)	Coef. (Std. dev)	Coef. (Std. dev)
Household head gender	954.25 (744.14)	22.74 (18.31)		26.88 (10.61)**
Household head age	-68.31 (27.08)**	-0.85 (0.59)		
Household head farming years	30.82 (30.65)	0.72 (0.58)		
Household head years of education	-7.22 (86.69)			1.62 (1.31)
Expenditure per adult equivalent	-5.08 (6.92)			
Membership to farmers group	-314.33 (607.35)			
Number of trees managed	2.44 (1.15)**		0.00 (0.00)	
Number of fertiliser types used	37.18 (504.21)			
Firewood gathering labour duration	24.2 (33.87)	2.76 (0.63)***		0.05 (0.44)
Agriculture labour duration	-13.12 (6.18)**		0.04 (0.04)	0.05 (0.09)
Off-farm employment duration	-3.13 (6.39)	-0.18 (0.18)	-0.02 (0.03)	
CAN fertiliser application rates	-0.14 (3.04)			
DAP fertiliser application rate	6.38 (2.98)**			
Manure application rate	0.24 (0.16)			
Proportion of adults		88.85 (31.3)***		0.16 (0.13)

Maize sufficiency by own production	-0.11 (0.20)	
Number of tropical livestock units	4.70 (4.95)	-0.15 (0.89)
Size of land owned	0.95 (4.95)	
Number of crops' enterprises	1.54 (7.11)	
Area allocated to other crops	-3.22 (5.90)	
maize_proportions1	-0.26 (0.30)	
Agri. contribution to livelihood	-0.03 (0.27)	
Spending on agriculture	0.00 (0.00)	
Household size (No. of individuals)	14.18 (3.81)***	-0.50 (0.59)
Distance for firewood gathering		2.76 (1.14)**
Own farm firewood sufficiency		-4.97 (2.23)**
Owning farm title deed		-3.07 (2.27)
Solar adoption		-3.23 (2.06)
Conscious of warming house		-3.64 (2.64)
Adoption of improved cooking stove		1.33 (2.14)
Daily cooking duration		1.69 (0.62)***
Household female ratio (%)		4.58 (5.48)
No. of houses in a household		-2.29 (1.80)
Proportion reliance of firewood		-0.02 (0.06)
Other non-firewood cooking sources		1.20 (1.25)

No. of members gathering firewood			5.18 (1.61)***	
Formal employment				121.3 (14.69)***
Spending on other expenses				0.00 (0.00)
Household member average age				-0.64 (0.31)**
Bumula	3385.13 (881.5)***			
Bungoma North	599.33 (849.49)			
Mt Elgon	416.69 (807.61)			
Contact	4832.2 (2132.6)**	-0.80 (51.68)	6.38 (9.07)	3.51 (22.70)
Parms	17	15	18	8
RMSE	4185.97	101.18	16.78	58.52
"R-sq"	0.0882	-0.158	0.173	0.346
chi2	66.85	53.93	99.1	116.27
P	0.0000	0.0000	0.0000	0.0000

Sabatia is the Base Sub-county

employment and biomass energy sourcing labour showed an inverse relationship with the maize yield, an observation that was not expected. It was suspected that households may be having a lot of labour that by its allocation in agriculture or any other option may not have a direct effect on maize yield reported. Results of this study contrast those of a study in Rwanda (Musafiri & Sjölander, 2016) which showed off-farm employment boosting agriculture and vice-versa. The complementarity between off-farm employment and increased agricultural production was associated with the success in poverty reduction strategies experienced in Southeast Asia (Estudillo & Otsuka, 2010).

The age of the household head and the amount of DAP fertiliser applied were significant ($P<0.05$) in influencing maize yield. Households with older heads of the family reported lower yields compared to those with younger heads. The observed, indirect relationship between maize productivity and age of farmers was consistent with other studies including in Nigeria on cassava (Ojiako et al., 2017; Olukunle, 2016) and rice (Ajah & Ajah, 2014). Higher rates of DAP applications led to increased maize yields. This observation was consistent with that of Amegnaglo (2018) who reported of fertiliser's significant effect on maize productivity in Benin. Other soil replenishing inputs including the use of manure and top dressing (CAN) positively influenced maize yield, however, the relationships were not significant. The observation where some form of fertilisers were reported to be significantly influencing yield, while others didn't was consistent with those of a study done in the same region to increase understanding of the importance of soil replenishing using collective trials (Misiko et al., 2011)

Significant ($P<0.01$) higher maize yields were reported in Bumula compared to the Sabatia sub-county. The differences in yields between the two sub-counties were associated with spatial variations presented by agro-ecological factors. In both Bungoma North and Mt. Elgon the maize yields reported were higher than those in Sabatia however the observation was not significant. The observation implied that with the low maize yield reported and associated smaller landholding in Sabatia, food security was restricted.

The amount of labour allocation to agriculture was significantly ($P<0.01$) influenced by time set aside for firewood gathering. Those households allocating more time to agricultural production also did apportion more time on firewood collection. There appeared to be complementarity between household labour apportionment for agriculture production and that allocated for firewood gathering. This outcome was consistent with a research outcome observed in western Uganda, where identical directions on labour allocations to firewood collection and agriculture were observed across gender and seasons (Okwii & Muhumuza, 2012). Other literature with matching outputs on agricultural labour allocation and firewood gathering included in rural China (Chen & Mirzabaev, 2016).

The number of individuals in the household involved in firewood collection was significant ($P < 0.01$) in influencing time allocated to firewood gathering annually. Efforts allocated to firewood collection could be associated with the demand for biomass energy sources and also the amount of labour in a household. Both the number of individuals involved in firewood collection and time spent on the activity were factors of efforts to avail the biomass energy. The two factors were expected to exhibit an indirect relationship as has been observed in other studies in Ethiopia (Mekonnen, 2020). In the Ethiopian study it was observed that as the number of individuals involved in dung and firewood collection increased, the duration for gathering each of the cooking energy sources significantly reduced.

The amount of time allocated to firewood collection was significantly and positively influenced by the amount apportioned to agricultural production. The relationship between time allocation to firewood collection and that allocated to agricultural production was unexpected. The two activities were expected to be competing and hence were anticipated to have an indirect relationship due to their mutual exclusiveness in allocation. Similar research outcomes where the amount of labour allocated to agricultural production and that apportioned to biomass energy sources were directly related were observed in Ethiopia (Gebreegziabher et al., 2018), Uganda (Okwii & Muhumuza, 2012) and rural China (Chen & Mirzabaev, 2016). The observation depicts agricultural production and energy sourcing in western Kenya and other rural areas to be mutually inclusive.

Households relying on their farm for firewood significantly allocated less of their labour on firewood gathering. With the ease of access to biomass energy sources, farmers allocate little effort to firewood collection. This was a desired time-saving observation that could be associated with the decision by farmers to plant and manage trees. However, the observation was inconsistent with a research outcome in Ethiopia (Mekonnen, 2020) where ownership of large numbers of trees and cattle were positively related to firewood gathering efforts and dung collection durations. In rural India, the number of trees owned was a significant factor influencing the households' energy mix (Hussain et al., 2017).

Households spending more duration cooking also allocated more time to gathering biomass energy with the relationship being significant (Jagoe et al., 2020). A longer duration of cooking implied more usage of biomass energy as it was the most popular energy source. As the amount of biomass energy required for cooking increased, more efforts through time apportioning to biomass energy sources gathering was necessary. Another factor that positively and significantly influenced the amount of labour allocated to biomass energy sourcing was the distance covered to the source.

5.3.5 Determinants of households’ capital allocation to various activities

Table 5.5 shows the determinants of financial spending on agriculture, biomass energy and other households’ expenses. Financial investment in agricultural production was significantly ($P<0.05$) and positively influenced by the household’s maize acreage and the amount of spending associated with other expenses. The two factors influencing allocations of capital to agricultural production could be associated with increased households’ welfare as they represent both resources endowment and prevailing potential for expenditure. Securing land for maize production is mostly through family ownership for this critical factor of production. The direct relationship between land apportioned to maize production and level of investment was expected as ownership of larger amounts of land permits farmers to make a greater allocation to agricultural production. Maize production necessitates the availability of finances for cultivation, purchasing of seeds, fertilisers and other agro-chemical; and payment for labour. Moreover, ownership of a large amount of land may provide evidence of resource endowed household. This observation was consistent with the outcome of a survey across agricultural households in Kenya (Muyanga et al., 2013) which showed a correlation between the amount of land ownership and agriculture investment. The study (Muyanga et al., 2013) concluded that land ownership was a critical contributor to asset wealth creation among rural households.

Households who spent more money on other expenses beyond agriculture and energy had high amounts of disposable incomes. With higher disposable income, households were capable of spending more on agricultural production. The observed outcome was consistent with other studies which showed income levels influencing agricultural investments (Giannakis et al., 2018). The value of firewood used was significantly ($P<0.05$) influenced by the number of members in a household, acreage under maize and household head years of education, distance travelled to gather firewood; and other households’ expenses. Both acreages under maize and the amount spent on other household expenses depicted variables representing households’ economic welfare. It, therefore, implied that the higher the

Table 5. 5 Trade-off of capital allocation to key investments among smallholders in Western Kenya

Endogenous variables	Agricultural investment in KES	Other households' spending in KES	Biomass cooking spending in KES
Exogenous variables	Coef. (Std. Err)	Coef. (Std. Err)	Coef. (Std. Err)
Household head gender	6137.82 (4011.45)	-14604.5 (11928.5)	4470 (2318.75)*
Household head age	-195.7 (119.51)		
Household head farming years	92.95 (110.6)		
Number of individual in a household	-83.21 (1165.34)	-625.58 (3399.3)	1444.4 (471.11)***
Household head years of education	-598.08 (685.77)	3965.0 (1814.6)**	-833.96 (331.06)**
Household average education year	-1323.94 (1200.63)	7129.4 (1852.5)***	
Other expenses	0.30 (0.14)**		0.09 (0.04)**
Agricultural expenses		-0.719 0.43	-0.34 (0.16)**
Biomass energy expenses	-0.82 (0.58)	3.8475 (1.2)***	
Maize sufficiency by own production	0.31 (0.95)		
Beneficiaries of credit services	3682.7 (3814.72)	18548.2 (10250.5)*	
Solar adoption	-2511.2 (2244.3)		
Annual expenditure per adult equiv.	-0.05 (0.11)	0.037 (0.303)	
Number of tropical livestock units	479.9 (957.8)		
Formal employment	2054.4 (5986.8)	23147.8 (14953.1)	
Area allocated to maize in 2017	8206.8 (822.2)***		3410.9 (1344)**

2017 Amount of maize production		6.4 (2.30)***	
Distance for firewood gathering			1547.9 (668.6)**
Own farm firewood sufficiency			-338.4 (1624.9)
Adoption of improved cooking stove			2501.8 (1499.1)*
Other non-firewood cooking sources			852.8 (934.3)
Number of trees managed			-1.78 (3.61)
Constant	32588.7 (18533.3)*	-126523 (27069)***	13856.3 (3988.1)***
Parms	15	10	11
RMSE	24604.32	77262.81	14984.58
"R-sq"	0.2792	-0.2331	-0.0629
chi2	302.51	69.33	48.52
P	0.00	0.00	0.0000

*** Significant at 1%; ** Significant at 5%; * Significant at 10%;

economic wellbeing of household, the more it spent on biomass cooking energy. The observed outcome was more consistent with the cooking energy stacking hypothesis rather than the energy ladder when economic status was related to the consumption of cooking energy. A consistent observation in urban Ethiopia showed households' fuel stacking behaviours to influence energy choice (Habte, 2015).

Acreage under maize influenced households to spend more on firewood either as influenced by limitations of potential for its gathering or increased purchasing capacity. The negative relationship between household head education and expenditure on firewood was associated with the fact that highly learned individuals had increased transition potential from biomass energy to cleaner sources (Rahut et al., 2016). The positive relationship between spending on firewood and households' ownership of improved cooking stoves raised concerns of the latter effectiveness as they are always promoted as being efficient energy savers (Komolafe & Awogbemi, 2010). The direct relation between improved cooking stoves and efforts in biomass energy has also been highlighted in rural China (Chen & Mirzabaev, 2016).

A significant ($P<0.05$) inverse relationship was observed between financial allocation to biomass cooking energy and agriculture. The outcome showed biomass cooking energy and agricultural production were competing for financial resources and chances for trade-off existed. Increased spending on biomass cooking energy meant that a decreased investment in agriculture was expected.

5.3.6 Determinants of food sufficiency and land allocations to agriculture and trees farming.

Table 5.6 shows the outcome of the 3SLS analysis on factors influencing the level of maize sufficiency through own production, amount of land allocated to maize production and the number of trees managed by smallholders. Variables that were observed to be significant in influencing levels of maize sufficiency through own production at significant ($P < 0.05$) included per adult equivalent expenditure and amount of land apportioned to maize production. The inverse relationship observed between levels of maize sufficiency through own production and expenditure per adult equivalent implied that those households that failed to produce enough maize spent more. The high expenditure could be associated with purchase of food including maize to meet household food demand. Households that allocated more land on maize production were observed to have a higher probability ($P<0.05$) of meeting their maize demand through their production. The relationship between the number

Table 5. 6 Determinants of food sufficiency and land allocations to agriculture and trees farming.

Endogenous variable	**Maize sufficiency by own production**	**Land allocated to maize**	**Number of trees managed**
Exogenous variables	***Coef. (Std. Err.)***	***Coef. (Std. Err.)***	***Coef. (Std. Err.)***
Household head gender	-4.79 (6.31)	1.08 (1.78)	48.52 (34.74)
Household head age	-0.01 (0.22)	-0.03 (0.06)	2.63 (1.4)*
Household head farming years	-0.26 (0.25)	0.07 (0.08)	34.96 (42.42)
Formal employment	-2.17 (7.34)	0.26 (1.93)	
Membership to farmers group	5.32 (5.21)	0.16 (1.85)	-17.32 (45.14)
Size of land owned	-1.15 (2.00)	0.41 (0.73)	27.54 (6.25)***
Area allocated to maize in 2017	3.93 (1.86)**		-24.54 (9.69)**
2017 Amount of maize production	0.00 (0.00)	0.00 (0.00)	0.01 (0.01)
Number of trees managed	0.09 (0.05)*	-0.02 (0.02)	
Household total Adult equivalent	-1.26 (1.39)		
Household head education	1.12 (0.61)*		-1.34 (2.52)
Number of tropical livestock units	-5.61 (3.56)	1.83 (0.41)***	47.11 (19.94)**
Expenditure per adult equivalent	-0.18 (0.06)***	0.02 (0.02)	0.39 (0.37)
Number of non-maize crop enterprise	-2.43 (3.15)	0.64 (0.92)	27.1 (17.02)
Number of individual in a household		-0.26 (0.29)	-8.59 (6.53)
Benefiting credit services		-0.05 (1.75)	29.22 (41.16)
Owning farm title deed			-17.82 (15.5)
Solar adoption			9.78 (18.87)
Bumula			43.89 (35.48)
Bungoma North		2.71 (1.39)*	120.3 (42.2)***
Mt. Elgon		1.67 (2.44)	144.3 (39.1)***
Sabatia		-3.49 (1.31)***	
_cons	87.84 (15.58)***	-2.44 (4.45)	-144.64 (95.44)
Parms	14	16	19
RMSE	36.77831	7.209698	267.6639
"R-sq"	-0.926	-0.4828	0.0298
chi2	42.25	51.65	126.22

P	0.0001	0.0000	0.0000

**** Significant at 1%; ** Significant at 5%; * Significant at 10%;*

of trees managed by households and the levels of maize sufficiency through own production was positive but weakly significant.

Farmers with a higher aggregate number of livestock including cattle, goat and chicken (TLU) allocated more land on maize production. Livestock husbandly was expected to require land that would compete with that to be allocated on maize production. The direct relationship between land allocated to maize and TLU is consistent with that in Cameroun (Yengoy, 2012), while in Ethiopia TLU significantly influenced the adoption of improved maize varieties and productivity (Ahmed et al., 2017). In South Africa allocation of land to more crops, trees and livestock were all directly related (Zerihum et al., 2014)

Spatial differences were also observed on the amount of land allocated to maize production. Significant less land was allocated to maize production in Sabatia ($P<0.01$) compared to that reported in the Bumula sub-county. Also observed was the apportionment of more land for maize production in Bungoma North compared to Bumula. The observed land allocations patterns for maize among the sub-counties were expected as they illustrated reported patterns of sizes of household land ownership in the region (Jindo et al., 2020). Moreover, some of the studies have presented the challenges of limited land ownership by considering the population density. The identical maize area allocations and total land owned patterns were attributable to the prioritisation of maize as a staple and the subsistence farming system in the region

Despite being not significant ($P\leq0.1$) a positive relationship was observed between the amounts of land owned and that apportioned to maize production. The numbers of trees managed were observed to be negatively associated with the amount of land allocated to maize production. The number of trees managed by farmers was significantly ($P\leq 0.05$) and positively influenced by the amount of land owned and the number of livestock owned. Smallholders with larger pieces of land were able to apportion more area for tree planting. Due to their nature trees require more space as influenced by the girth, height achieved, branching and their perennial nature. The results of the study are consistent with those in the same region (Jerneck & Olsson, 2013) where decisions on tree planting adoption were argued as based on natural and social endowments which influenced profitability, feasibility, and acceptability. The observation of land size owned influencing tree planting is consistent with results for a study in Central Kenya (Oeba et al., 20l2) and South Africa (Zerihum et al., 2014).

An inverse and significant ($P \leq 0.1$) relationship was observed between the number of trees managed and land allocated to maize production. The observation is attributed to the fact that trees are perennial and compete for space with all the other crops. This observation is consistent with outcomes of a study in Malawi (Meijer et al., 2015) where despite farmers who reported planting trees in the last five years having more positive attitudes, subjective norms and perceived behavioural, demands to respond to the basic needs including food security assurance were prioritised. The trade-off between tree growing and maize production has been reported in the Philippines (Martin & van Noordwijk, 2009). Kassie (2016) investigated the trajectory of substitution of agroforestry adoption decisions in Ethiopia and argued for a systematic transition from agroforestry to the commercial tree growing as impacted mostly by non-food agricultural returns.

Households in Bungoma North and Bumula sub-counties managed significant ($P \leq 0.01$) more trees compared to those in Sabatia. The regional difference in the number of trees was associated with the land sizes owned by the households. Sub-counties with smallholders having proportionate larger sizes of land reported more trees being managed.

5.4 Conclusion

Critical to driving the effect of cooking energy on subsistence farming were three components that were described including the socio-economic characteristics of household, the agricultural characteristics and energy sourcing behaviours. Most households' labour was allocated to leisure, thus raising concerns on the reservation price for smallholders to engage in productive employment. Only a fifth of household labour was allocated to key productive activities including agricultural production (16%), biomass energy sourcing (1%) and off-farm employment (7%). The smallholding agricultural production practised in the region had failed to spur robust off-farm employment consequently both of these income-earning engagements were unable to drive cooking energy demand that necessitated more allocation of labour beyond a percentage. Such a labour allocation pattern among households depicted a situation where a high proportion of it was reserved in leisure, implying that chances of competition and trade-off of this critical resource were low. Nevertheless, the rainfed agricultural production system practised could have affected the monthly allocation of labour patterns to have highs and low demand seasons. Overall labour resources allocation was not a major constraint in influencing maize productivity.

The inverse relationship observed between household labour time apportionment to agricultural production and maize yield indicated a challenge in the allocation of this productive resource. Apportionment of more labour to agricultural production didn't guarantee improved maize yield. A positive relationship was observed between the maize yields reported and the number of trees managed. This outcome showed synergy between food production and biomass energy provision strategies. Spatial factors were also observed to affect maize yields with the levels reported in Bumula being higher than those in Sabatia. Other factors that influence yield reported included levels of DAP applications and the age of household head.

A positive relationship was observed between labour allocated to agricultural production and that which was allocated to biomass energy sourcing. Households that had more members and those with a higher proportion of adults allocated more time to agricultural production. Labour allocated to biomass energy sourcing was more associated with energy sourcing behaviours including the number of people routinely involved in its fetching; distance covered in search of firewood; cooking duration and dependence of own farm to firewood demand. Households' financial allocations to agricultural production and buying biomass energy sources were positively influenced by expenditure on other needs (except agriculture and biomass) and the amount of land dedicated to maize production. In this regard household disposable income and wealth potential presented land size owned affected investment in agriculture and biomass energy. However, the spending on biomass energy was inversely affected by the levels of spending on agricultural production.

An inverse relationship was observed between the amount of land allocated to maize production and the number of trees managed by households implying the presence of a trade-off between trees and maize area. Spatial differences were observed in the area allocation to both maize and the number of trees managed. Households in Sabatia allocated less land to maize farming and managed fewer trees than those in other sub-counties.

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CHAPTER SIX

DETERMINANTS OF GREENHOUSE GAS EMISSIONS IN WESTERN KENYA

Abstract

The lack of a methodology to evaluate smallholders' greenhouse gas emissions is hindering efforts for mitigating climate change through reduction of emissions as per the international community agreements and protocols. Unlike with other agricultural production systems and the developed countries' consumptions behaviours that could be accounted for through farm records and consumption receipts, the smallholding is complex as both production and consumption are integral parts of the system with little record keeping. In this study, a methodology of estimating greenhouses gas is discussed and used to provide insights on maize-farming system smallholder emission status. A combination of both the 'bottom-up' and 'top-down' approaches was used to derive the levels of greenhouse gas emissions associated with the maize farming and cooking energy activities. A survey of households on the levels of agricultural production and use of various inputs; and type and amount of cooking and lighting energy utilised provided information on emission activities' intensity. Using the secondary data available at the FAOSTAT website and in other literature, emission factor indices were derived and multiplied with respective activity data to get the levels of emissions. Another specific objective addressed was to evaluate the determinants of GHG emissions among smallholders. The main GHG emission sub-domain in the smallholding was maize production which accounted for 47% of the total emission; others were cooking energy (37%), livestock (13%) and lighting (3%). Using an ordinary least square (OLS) model, significant ($P \leq 0.05$) determinants of the levels of GHG emissions were the household's size, total land owned, number of tropical livestock units, levels of maize yield achieved, distanced covered in firewood gathering and the geographical factors. Efforts to reduce household GHGs emissions should address the adoption of cleaner cooking and lighting energy and enhance efficiency in livestock production and the use of inorganic farming inputs for crop production.

6.1 Introduction

Understanding greenhouse gas emissions is important for the international community as the knowledge will aid in designing sustainable development strategies that will ensure economic growth while sustaining the environment (Forrest, 2015; Kmoch et al., 2018). Atmospheric accumulation of greenhouse gas is the sole contributor to global warming, that have been associated with the climate change phenomenon. Agriculture, especially smallholder farming is threatened by the devastating impacts of climate change (Donatti et al., 2019). Key components of agricultural production, including farming communities, agroecosystems and the infrastructural to facilitate the sector (Kmoch et al., 2018), are being affected by climate change. Furthermore, the climatic factors that highly drives the smallholding farming systems due to restricted technological adoption as affected by limited financial capabilities, including rainfall, temperature, relative humidity and wind are getting altered by climate change. The effects on the predictability and the intensity of the weather factors affecting production threaten the smallholding farming system survival necessitating interventions for greenhouse gas emissions reduction.

Global efforts in the management of GHG are currently being cascaded to all citizens (UNEP, 2019) after some years of imploring developed countries that were considered as major emitters by the Kyoto protocol (ADB, 2018; Ligardo-Herrera et al., 2018) to reduce emissions. Despite a consensus among the international community on the need for countries to establish emissions levels for their production and consumption systems, a major difficulty has remained on a universally accepted method of estimating GHG emissions (Rosenstock et al., 2016). Several methods have been adopted for various countries based on their development status and the key production activities undertaken. Based on the scope of the studies undertaken, the approaches adopted are either top-down, bottom-up or a hybrid of the two (du Pont & Meinshausen, 2018). The scope of the bottom-up is more local and data collection and processing cover a small area (as small as a household, office, laboratory and district); allows collection of emission data at a finer resolution; and only reflects emissions associated with projected activities data at the "pilot" site. While the bottom-up approach has been credited for involving and permitting local managers to undertake relevant emission-reducing interventions, several weaknesses have been highlighted. Among key concerns for bottom-up emission inventories included the approach failure to account for historical data for a site, and data collection and evaluation procedures can differ between sites, time and resource inputs.

The top-down GHG inventories are more global in aspects and are mostly undertaken at the national level or an entire economy and they generally describe substitution across different inputs based on historically calibrated factors. The approach focuses more on the market processes rather than technical details. This approach has been criticized due to the absence of involvement of the local managers and the inaccuracy of aggregated data to reflect local conditions (du Pont & Meinshausen, 2018). Both the bottom-up and the top-down approaches are domiciled in energy and transport sectors emission reviews. The integration of both the approaches referred to as hybrid allows for an enhanced strategy which permits the combination of both technical details and more general descriptions of economic processes. Key considerations for whichever approach adopted include the quantity of GHG emissions being emitted, possible change in activity's intensity and the cost implications.

Despite a rapid increase in the number of research and publications on households' GHG emissions over the last three decades suggesting the growing awareness and recognition of these types of studies, information lacuna exists largely on assessments, assessment criteria and determinants of emissions (Liu et al., 2020). Moreover, the applicability of these studies' output in the policy environment has also been observed to be a challenge even though the use of household GHG emission research provides a comprehensive understanding of the overall knowledge of the environment, the economy, society, and technology.

Households' GHG emissions are classified based on different energy types, different life demands, and different consumption behaviours (Liu et al., 2020). The classified GHG emissions could be further categorised into those associated with the consumption of products and services (Qu et al., 2019). The Emission linked to utilisation of food, clothing, housing, household equipment, health services, education, communication, transport and other amenities e.g. entertainment and culture etc. Life demands emissions are categorised based on whether they are associated with activities necessary to meet basic living demands and undertakings to meet the development of living demands. Consumption behaviour in food, clothing, transport, housing and services accounts for five emission categories under this classification.

Critical to the estimation of households' GHG emissions is the availability of predicting or computing methods for emissions (Ren et al., 2013). Key among them includes the sectoral and reference approaches (Tippichai et al., 2009) that have been developed and promoted under the Intergovernment Panel of Climate Chenge (IPCC) frameworks (IPCC, 2014). The consumer lifestyles approach (CLA) focus on understanding the role of a consumer of products and services in energy use and environmental impacts. The advantage of this predicting method is that it incorporates both the behavioural and macro-levels factors when estimating emissions (Schwarzinger et al., 2019). The lifecycle approach calculates GHG emissions generated in the whole process of product production and service through the entire life cycle also referred to as 'from cradle to grave'. On its part, the input-output method (IOM) evaluates indirect emissions data using micro-macro statistics data for sites e.g. cities, nations and regions (Liu et al., 2020). Other methods include the cost-benefit analysis which applies the social cost of carbon in evaluating the present value in monetary terms of the damages incurred for additional emissions. The method requires data inputs from many different disciplines including climate science, social science, ecology and agriculture. Notwithstanding the availability of techniques and approaches for households' GHGs emissions, literature obtainable associate these types of studies to developed countries (Allinson et al., 2016; Li et al., 2016; Qu et al., 2019; Ren et al., 2013) due to accessibility of consumption data attributable to utility supply systems and accountable purchasing behaviours.

Smallholders are involved in both production and consumption, and operate in an information deficient environment on what is produced, what proportion of the production is consumed, the proportion of purchased goods and services utilised and technology for consumption. Moreover, the methods of production and associated emissions levels linked to the input used and technology adopted require evaluation. Approaches for evaluating emissions associated with smallholders agriculture production have been varied (Rosenstock et al., 2016) including enterprise based for example dairy (Udo et al., 2016), cereals (Sapkota1 et al., 2018), coffee (Maina et al., 2015), and crops' enterprise and technological use (Tongwane et al., 2016). Emissions evaluated at specific farm sites (Meier et al., 2020), whole farms (Prado et al., 2013) and landscapes (Rufino et al., 2016) have also been reported. Other studies have relied on indirect methods mostly adoption of carbon sequestration technologies to evaluate negative emissions (Linderholm et al., 2020).

The goal of this study was to evaluate determinants of greenhouse gas in smallholder farming systems. The specific objective included the utilisation of available information to describe a methodology of revealing GHG emissions among smallholders; to evaluate GHG emission levels among smallholding maize-intercrops farming systems in western Kenya and evaluate the determinants of GHG emissions among smallholders. The research outcomes would be critical in availing a methodology of assessing emissions associated with smallholding agricultural production systems and the associated utilisation of biomass energy sources for cooking. Efforts to mitigate GHG emissions would benefit from the outcomes as predictions of the factors influencing levels will be provided. The research outcomes will be timely as increased levels of GHG emissions continue to be reported in developing regions including Africa (Lamb et al., 2021) raising concerns on methods of interventions considering the poor data on consumption.

6.2 Methodology

Various methodological procedures were adopted to achieve the set specific objectives including sourcing for data, its management and analysis.

6.2.1 Data sources and types

Data used in the study was derived from primary and secondary sources of data collection. The primary data sources included a survey, while the use of Food and Agriculture Organisation of United Nations (FAO) statistics constituted a secondary data sourcing.

Primary data sources

A survey of smallholders

A survey research design as described in Chapter 3 was adopted as the primary data source. A questionnaire was used in collecting cross-sectional information on routine production activities associated with crops' management, livestock husbandry and biomass energy production and consumption with the survey outcomes extrapolated as 2017 annual values. The personal interview collected information at the household level with the targeted respondent being the household head who provided information on the household. The questionnaire had modules that included questions on households' socio-economic characteristics, agricultural and energy production, and consumptions behaviours. The socio-economic information collected was associated with the household head and the household including the household head's education levels, gender, age, experience farming, and formal employment among others. Household information collected comprised household size, land owned, weekly consumption expenditure, sufficiency in staple from own production and status of land ownership.

Agricultural production modules queried householders on the types and number of livestock reared, types of crop enterprise cultivated and maize production information. Maize production data collected included the acreage, production levels and yields achieved, and the levels of organic and inorganic fertiliser applications. The number of trees surviving after propagation was the other agricultural production information gathered from the households. Energy production and consumption data collected comprised of the cooking, house-warming and lighting energy sources; and quantity gathered, and used. The presence of energy-saving technologies adopted by households was also assessed.

Weighing of biomass energy sources

In the course of undertaking the survey, biomass cooking energy sources were weighed to corroborate information provided by household members on the quantity used. The weighing was done using a portable electronic spring balance which could weigh upto a mass of 30kg. Biomass energy sources weighed included firewood, charcoal and agricultural residue.

Estimation of weights was able to provide the real mass of the fuel used through corroboration with the volume household reported. The mass established through weighing was used in the GHG emissions associated with cooking energy. Based on the type of biomass energy, the mass reported was multiplied by respective emission factor indices (Edwards et al., 2015) to derive GHG emission amount.

Secondary data sources

FAO statistics

Food and Agriculture Organisation of United Nations (FAO) website (*http://www.fao.org/faostat/en/data.org*) was accessed on 20th June 2020 and emission information associated with production, inputs and emission factors were extracted. Among the information used included that of livestock (cattle, goat/sheep and chicken) and crop enterprise (maize) production; inorganic fertiliser (basal and top-dressing) and organic (manure applications) inputs management; and emission factors for various production activities practised by smallholders.

Literature Review

Publications associated with greenhouse emissions including manuals (Rosenstock et al., 2016; Tubiello et al., 2015) and frameworks (IPCC, 2006) were used to provide the procedures for assessment.

6.2.2 Designing the methodology for GHG emissions among maize-based smallholding in western Kenya

A hybrid approach that incorporated both the 'bottom-up' and 'top-down' methods of estimation and validation of GHG emission was adopted for this study. Cognizant of the critical role citizenly could play in reducing GHG emissions (Meieret al., 2020), the lacuna in the information of smallholders status in GHG emissions (Cohn et al., 2017), contradiction on the role of smallholders in GHG emission and removal status (AGRA, 2014; UNEP, 2019) heterogeneity in smallholding systems (Ricciardi et al., 2015), the diversity in the characteristics of farming systems in any of the country (Rapsomanikis, 2015), and the benefit of each of the approach, a mixture of the two was adopted. Moreover, the objective of the study permitted evaluation of the best and most effective approach to developing a cost-effective method that could timely inform the National GHG Inventory reporting and target specific farming systems.

Through the bottom-up approach, the study was localized initially at the household level and cascaded for characterisation at the sub-county level. Despite the comprehensiveness necessity for the local studies and resultant high-cost implications, the survey only targeted maize-agroforestry and biomass cooking energy production and consumption. Through the survey and supplementing methodologies, intensity in various activity data was established per household, as a production and consumption unit. The smallholders' activity data intensity averages in respective sub-county were generalised to represent the agro-climatic zones and resultant farming system characteristic to a sub-county. In this regard, the emission analysis scope was restricted to the direct outcome (direct emission), a scope that overly simplified the estimation process. Such rapid assessment techniques are appropriate where aggregate data are available on agricultural land use and management practices but where field measurements of GHG and carbon stock changes are not available (Grewer et al., 2016).

Emission factors indices generalised for the national level (IPCC 2006; Tubiello et al., 2015) were used for multiplication with activity data intensities gathered through the survey to derive the emission levels for each of the activity data (IPCC 2006). The GHG inventory sector for this study was the Agriculture, Forestry & Other Land Use_AFOLU (IPCC 2006) which deals with anthropogenic GHG emissions and removals, defined as all emissions and removals occurring on managed land. The data collection procedure was consistent with the IPCC's main steps in compiling a GHG Inventory (Tubiello et al., 2015) that ensured only the relevant activity data were used for estimation. In this regard, the household survey ensured the collection of quantitative data that responded to various production and consumption activities postulated in the emission manual under AFOLU (Tubiello et al., 2015). The study adopted Tier 1 and Tier 2 methods for the GHG emission calculations in respective to the decision tree procedure used and emission factor data availability.

6.2.3 Estimation of activity data among smallholders

Smallholder GHG emissions were estimated by using methods described in the FAO manual describing agricultural data requirements for GHG estimation in developing countries (Tubielloet al., 2015).The 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) provides comprehensive instructions on estimating GHG emissions and removal. GHG emissions and mitigation assessment targeting smallholders are domiciled within the Agriculture, Forestry and Other Land Use (AFOLU) sector as this is where direct human-induced land use, land-use changes, and forestry are applied (Smith et al., 2014). Crucial to the 2006 IPCC guidelines' scientific strength and utility for this study was its procedure for identification of major categories of emissions; the selection of methods and measurements; selection of activity and collection of activity data; and provision of the default emission factors. Option activity data and respective default emission factors are specified at global, region and/or subcategory/subdivision levels. Moreover, its utilisation has been enhanced by the Food and Agriculture Organisation of United Nations (FAO) publication of manuals (Tubiello et al., 2015) and data inclusion on their website (FAOSTAT).

Table 6.1 shows the activity data selected for estimation of the emission for the study against other information available based on the 2006 IPCC guidelines. Key to the decision of estimating a specified activity data was correspondence reporting during the survey of the smallholders, activity listing, and availability of emission factor with IPCC guidelines and WHO (Edward et al., 2015) and the certainty potential of the activity (Tubiello et al., 2015). Based on the activity. data and those listed by smallholders, the major emissions options could be categorised into those associated with livestock management, maize production, cooking energy and lighting energy. Despite the availability of emission factors and accounting criteria in the manuals used for some activities including rice cultivation, manure left in the pasture and cultivation of organic soils, the study didn't consider them for estimation.

Although the presence of organic soils mostly Histosols (Eswaran & Reich, 2005) has been reported in western Kenya (Rao et al.,2015) largely in Mt. Elgon, Bungoma North and Bumula, their occurrence was erratic, accounted for only an insignificant proportion and could not be succinctly associated with a sampled area without soil experts. Moreover, the choice of the methodology didn't comprehensively evaluate emission associated with soil management (Oertel et al., 2016) due to their complexity and cost implications, the narrowness in scope and the fact that soils associated emissions vary by season, farm area in a household and the history of input applications.

Table 6. 1 AFOLU activity data and emission factor for various GHG and the study decision tree

Activity data (AD)	Emission factors provided	Study decision	Driver of the study decision based on survey household intensity of AD
Enteric fermentation	Domesticated animals by types and region	✓	Goat and dairy cattle
Manure management	Type of livestock and how manure is handled	✓	Total excretion dairy cattle goat, chicken
Rice cultivation	Area	✗	No rice farming for the sampled area
Synthetic fertilizers	Fertiliser type	✓	Basal (DAP) and top-dressing (CAN)
Manure applied to soil	Type of animal manure	✓	Amount reported used estimation, some manure purchased
Manure left on pasture	Type of animal manure	✗	Could not be estimated
Cultivation of organic soils	By major global biomes	✗	Histosol, the available organic soil was patchy and couldn't be associated with sampled localities.
Crop residues (burning or decompositions)	Key cereal crops + sugar cane (C4-crops)	✓	Maize waste except underground Estimated but considered as a mitigation
burning - Savanna	Sub-biomes associated with savanna	✓	Estimated but considered as a mitigation
energy use in agriculture	By fossil fuel used in agriculture	✗	Low mechanization hence not considered in western Kenya

Animal excreta management	Livestock type and region	✗	Total excretion dairy cattle goat, chicken (NB: Not repeated as already above (2nd row)
Biomass cooking energy	Environment for combustions	✓	Adopted (Edwards *et al.,* 2015) that estimated emission at households

NB: ✓= AD selected for the estimation; ✗ = AD not selected for estimation

Source: Tubiello et al. (2015)

Table 6.2 shows values of emission factors for various domains of activities in Kenya and the type of GHG emitted. Items chosen included the cattle with the selection of the non-dairy cattle. The non-dairy cattle, also referred to as 'other cattle' were kept principally to produce calves for meat or to provide draft power. Moreover, they are low productivity multi-purpose cows. Chicken reported were considered as layers under free-range conditions for egg or meat production. Goats and sheep were considered in one category due to their identical emission characteristics. The fertiliser types reported for maize production including DAP and CAN were domiciled with the Synthetic Nitrogen types. Manure reported by farmers to have been applied on farms as soil fertility replenishing input was assumed to have been derived from non-dairy cattle. The use of the country's item data derived from FAO sources introduced the top-down and integrated Tier II approach in this methodology.

Table 6. 2 Type of GHG emitted and emission factors for various domains of activities in Kenya

Domain	Items in Kenya	Unit	Value (Emission factor)
Enteric Fermentation	Cattle non-daily	kg CH4/head	31
Enteric Fermentation	Goat	kg CH4/head	5
Manure Management	Cattle non-daily	kg CH4/head	1
Manure Management	Cattle non-daily	kg N2O-N/kg N	0.0115
Manure Management	Goats	kg CH4/head	0.17
Manure Management	Goats	kg N2O-N/kg N	0.0025
Manure Management	Chickens, layers	kg CH4/head	0.02
Manure Management	Chickens, layers	kg N2O-N/kg N	0.005
Manure applied to Soils	Cattle non-dairy	kg N2O-N/kg N	0.0143
Cultivation of Organic Soils	Cropland organic soils	kg N2O-N/ha	9.3329
Crop Residues	Maize	kg N2O-N/ha	0.0123
Synthetic Fertilisers	Synthetic Nitrogen fertilizers	kg N2O-N/kg N	0.0132

Source: FAO (2020)

After calculation, all the measures of greenhouses gas were converted to a standard unit, the carbon dioxide equivalent (CO_2e). The unit is a metric measure used to compare the emissions from various greenhouse gas based on their global-warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential (Tubiello et al., 2015). The global-warming potential for Methane (CH_4) and nitrous oxide (N2O) has been estimated at 21 and 310 respectively which are their conversion rates to a carbon dioxide equivalent.

Table 6.3 shows the emission factors adopted for biomass cooking energy and the fossil fuels for lighting used by smallholders. The cooking was considered to happen in an environment comparable to most kitchens with stoves adopted by households based on designs (Hoopers et al., 2018) including traditional unvented, traditional vented, traditional unvented for firewood, crop residue and charcoal respectively. The lantern lamps used to light the houses and fueled by kerosene were considered to be similar to traditional unvented stoves. The use of LPG in cooking was quite minimal and smallholders were unable to succinctly estimate its usage per duration hence despite being associated with emissions, their levels could not be estimated. Other maize by-products except for the seeds, that is the stacks and cobs were considered to be the only crop residues used for cooking by households.

Table 6. 3 Average emission factors for household stoves laboratory/simulated kitchen measurements

Fuel type	Cooking stove classification	Carbon dioxide (CO_2)	Carbon Monoxide (CO)	Methane (CH_4)	Total non-methane organic compounds (TNMOC)	Particulate matter (PM)
				Emission factor (g/kg)		
Firewood	Traditional unvented	1610	52.8	8.9	8.5	2.5
Firewood	Traditional vented	1560	23.6	0.6	0.1	1.5
Dung	Traditional unvented	1000.5	42.99	11.63		2.45
Crop residue	Traditional vented	2005	68.7	6.2	3.2	3.2
Charcoal	Traditional Unvented	2559	162.3	6.9	10.3	2.12
Kerosene	Traditional Unvented	3180	27.2	0.48	0.34	0.29
LPG	Traditional Unvented	2532	14.2	0.04	3.7	0.34

Source: Edwards et al. (2015)

Measures of electricity used from the national grid by the few households connected and by solar panels owned by farmers made it impossible to estimate the emission associated with its use. Moreover, the proportional sourcing of electricity in the national grid either as hydropower, geothermal, thermal or biomass generation could not be ascertained to allow emission estimation. It is important to note that while the simulated kitchen conditions represented sizable proportions of cooking environments, some households had adopted cooking in open fields while not all kitchens were identical. The differences in the cooking environment notwithstanding, the emission factors provided a critical link to estimating cooking energy associated emissions in a household.

The survey output provided information on the intensity of each of the activity data for agricultural production, livestock husbandry and energy consumption activities. The estimated intensity for each of the activity data was multiplied by respective emission factors/ indices to get the household GHG emissions per activity. The summation of each of the activity's GHG emissions outcomes accounted for the household's total.

6.2.4 Empirical model

The study adopted the use of valuation methods of extractive consumption including fuel (van Vuuren et al., 2017). After quantification of the total household energy mix, greenhouse gas (GHG) emission was calculated following accounting technique developed by IPCC (Meier et al., 2020; Prado et al., 2013) and adopting fuels' emission coefficients by World Health Organisation (Edwards et al., 2015). A multiple linear regression model was adopted for empirical analysis.The multiple regression model could be simply represented as shown in equation 10 (Uyanik & Guler, 2013).

$$y = \beta_0 + \beta_1 X_1 + ... + \beta_n X_n + \varepsilon \qquad (6.1)$$

Where y is the dependent variable representing greenhouse gas emissions (CO_2e) per adult equivalent. X represents a matrix of independent, explanatory variables including those associated with characteristics of a household head, the household and the environment. β are coefficients of the independent variables and ε, the error term.

Per capita greenhouse gas (GHG) emission intensity was estimated to be a factor of a vector of socio-economic characteristics of household head (age, sex, education level in years etc), households characteristics (land owned credit access, size, adoption of solar panel or improved cooking stoves etc), a vector of the levels of various energy sources utilised (firewood, agricultural residue, charcoal and kerosene) and levels of agricultural yield achieved, among others. Table 6.4 shows the empirical model for per capita greenhouse gas emissions.

Table 6. 4 Empirical model for per capita household greenhouse gas emissions

Variables	Relationship with dependent variable
Y= Per capita greenhouse gas emissions	
Age of household head	-
Education level of household head (years of schooling)	+
Sex of household head (dummy variable) male- headed household	+
Off-farm employment	+
Formal employment	+
Household size	-
Per capita expenditure	+
Farming experience _years	-
Enjoying credit facilities	+
Hours of activities daily	+
Total land owned	-
No. tropical livestock unit	+
Number of crops' enterprises	-
Maize production sufficiency	+
Farmer group membership	+
Maize yield achieved	+
Solar installation	-
Improved cooking stoves	-
No. of cooking energy sources	+
Distance covered for firewood	-
Own farm firewood sufficiency	+
Sub-county dummies	

6.3 Results and Discussion

6.3.1 Description of characteristics associated with household, farming and energy utilisation

Table 6.5 shows descriptive statistics for the variables used in regression to estimate determinants of greenhouse gas emissions (GHGs) among households in western Kenya. The results show wide differences in age and farming experience. This was expected to be reflected in decisions associated with cooking energy source choice and amounts used (Menashe-Oren & Stecklov, 2017). Older farmers have been observed to be more risk-averse, resulting in low adoption of agricultural (Lemessa et al., 2019) and energy-related (Uhunamureaet al., 2019) technologies. However, experience may lessen the averseness since familiarity is likely to results in better-informed decisions. The supposition of age advances of rural household heads as being critical to agricultural transformation and therefore improved socio-economic welfare due to experience contradicts what has been presented on the benefits of demographic dividends (Menashe-Oren & Stecklov, 2017) considering the population patterns in most developing countries. However, the key to greenhouse gas emissions and the ages' structure of the rural households depends on the household's decisions on the production and consumption technologies and their resultant impacts on emissions.

The results suggest that most household heads had attained primary-level education. An important observation in case of necessity for adoption of unique production and consumption technologies in response to greenhouse gas emissions reduction as basic education has been reported to yield best returns in technologies adoption consistent with the Schulz hypothesis (Paltasingh & Goyar, 2018). Moreover, education has been associated with increased disposable income (Turcinkova & Stavkova, 2012), that have been related to increased levels of emissions. Other socio-economic characteristics included the high levels of male-headed households (78%), low enrolment to farmers group (25%) and use of credit facilities (23%) have impacts on both agricultural and energy utilisation status. The use of farmers' groups as an avenue for improving social changes in rural areas has become critical due to its cost-effectiveness and efficacy (Franzel et al., 2018) however the low membership was a concern considering the efforts that have been put to interest groups' establishment, fine-tuning for relevance and capacity building. Other social-economic characteristics that may have repercussions on household behaviours and resultant emission levels included the

Table 6. 5 Household characteristics, farming and energy utilisation linked to GHG emissions

Household characteristics	Mean	Std Deviation	Min	Max
Household head gender	0.78	0.42	0	1
Household head age	49.82	15.53	20	93
Household head farming years	20.84	15.119	1	75
Household size	5.26	2.091	1	13
Household head education (years)	9.58	3.751	1	16
Firewood gathering outing duration (min)	79.21	82.37	0	480
Distance in firewood gathering (km)	0.55	1.06	0	12
Solely use of own farm for firewood	0.59	0.49	0	1
Daily per capita expenditure (KES)	55.25	40.58	6.35	476
Sufficiency of maize by own production (%)	76.8	25.56	0	100
Enjoying credit facilities	0.23	0.42	0	1
Membership to farmers group	0.25	0.43	0	1
Number of tropical livestock units	1.89	0.87	0	3
Land size ownership (ha)	2.42	3.17	0.13	20
Installation of solar panels	0.52	0.50	0	1
Conscious in warming house	0.213	0.41	0	1
Using improved cooking stoves	0.418	0.49	0	1
Maizeproduction in 2017 (kg)	1597	3074.36	0	40500
Area allocated to maize in 2017 (ha)	0.56	0.87	0	11.74
Non-maize crop enterprises	2.58	0.83	1	5
Number of trees propagated	137.5	264.24	0	2010
Daily duration in cooking (minutes)	183	97.74	30	555
Non-firewood cooking sources	1.31	0.91	0	4
Household's emission in (tonne CO_2e)	34.89	1981.98	19.9	38508
Emission per capita(tonne CO_2e)	52.23	44.25	3.34	402.2
Emission per Adult equivalent (CO_2e)	65.42	67.00	3.54	884.

low per capita expenditure, small total landownership and the duration of cultivating a farm (Ogle et al., 2019).

Efforts in accessing biomass cooking energy sources among households may have emissions implications in that ease of availability would encourage the households to use more amount of firewood unlike if otherwise. The resultant higher usage of firewood would yield increased levels of GHG emissions. On the other hand, if firewood was not readily available households may not only reduce the quantity used but could shift to cleaner sources thereby significantly reducing the emission levels. The biomass energy sources availability factors include the distance travelled to gather firewood, duration per outing and sole reliance on own farm for the biomass source. The wide variations reported on the duration per outing and distance covered in firewood collection was expected to increase differences in the amount of biomass cooking energy utilised among households.

The longer average duration for cooking daily reported (about 3 hours), was associated with the community dietary behaviour and cooking energy used. Cooking coarse foodstuffs including cereals requires more time for cooking. The use of firewood was mostly associated with foodstuffs taking longer to cook due to cost considerations. Longer cooking durations were therefore associated with high usage of biomass cooking energy and hence more GHG emissions. Households contemplating warming the house environment have only biomass energy choices for consideration due to their heat transmission potential. The low proportion (21%) of households reporting consciousness of warming the house environment as they considered cooking energy implied a restriction to increased usage and choice for biomass cooking sources. However, it could be that households make the decision on biomass cooking energy independent of house environment heating desires and since the energy sources warm the house anyway, the concern for house warming does not arise.

Adoption of energy-saving and shifting to clean energy technologies such as improved cooking stoves and installations of solar panels reduces emission levels in a household. Adoption of solar energy sources and improved cooking stoves reported at 52% and 42% respectively in a region associated with poor acceptance of technologies (Odendo et al.,2011) was quite positive. It is possible that energy sourcing challenges could have pushed the households to adopt the technologies. The average number of trees reported to be managed by every household was also considered as a positive energy provision intervention achievement. Despite, tree planting being considered as a desired emission mitigating intervention; in this study availability of trees was associated with the increased amount of biomass energy available and used, and hence increased emissions. Planting of trees signalled farmers' effort to ensure self-sufficiency in household biomass energy provision.

The intensity of agricultural production including area under maize, maize yield achieved and the livestock diversifications and numbers were directly associated with levels of emissions. Despite the scale of farming activity being considered as a smallholding, the range of maize production activity in 2017 was confirmed with an average of 0.56ha. The acreage determined the coverage of soil manipulated, levels of fertility replenishment inputs used and extent of mechanization. On its part, maize yield achieved provided testimony on inputs utilisation and the adopted technologies' efficiency in responding to production goals. Since food production is vital for humanity, an efficient system is desired to ensure less emission per input utilised and hence output. Any livestock reared was associated with emissions and hence the number and the type of livestock were direct determinants of emissions.

6.3.2 Households livestock management associated emission

Table 6.6 shows emission estimated for various key livestock management categories and their associated sub-domain. Emission levels were observed to be livestock type dependency, with cattle associated with the highest levels while goats and chicken followed in that order. Livestock emissions' sub-domain included enteric which was associated with ruminants including goats, sheep and cattle. During digestion in the ruminant's digestive tract, enteric fermentation takes place where microbes decompose the consumed vegetation material (cellulose, fibre, starch and sugar) with mostly methane being released (Gerberet al., 2013).

Enteric emissions associated with cattle were ten times higher than for a goat, an indication of wide differences between livestock types on this sub-domain of emission. On average, methane associated with Enteric emissions was 114kgyr^{-1} per household with 95% linked to cattle. Other GHG emissions sub-domain associated with livestock included nitrous oxide (N_20) and methane arising from manure management. Out of the total GHG emission associated with livestock estimated at 3000kgyr^{-1} CO_2 equivalent per household, 98% was associated with enteric with the rest accounted for by manure management. Cattle accounted for 95% of the GHG emission associated with livestock while the other five percent arose from goats. Chicken associated GHG emissions were minimal at less than a kilogramme of CO_2e per household annually. Chicken is not associated with enteric emission as it is a non-ruminant. Every head of cattle, goat, and chicken reared by households in western Kenya was estimated to emit 1176kg, 131 kg, and 0.002 kg of CO_2 per annum respectively. The observation on the ratio of emission for livestock sub-domains was consistent with other studies within the East Africa region (Udo et al., 2016).

Table 6. 6 Households average emissions associated with Livestock management

	Cattle	Goats	Chicken	Total
Livestock sub-domain	Emissions in $kgyr^{-1}$			
Average number of livestock	2.4	1.2	10.8	-
Annual emission per livestock	1175.7	130.6	0.002	-
Enteric_CH_4(kg/yr)	108.2	5.96	-	114.18
Enteric CH_4 in CO_2e	2705	149.07	-	2854.6
Manure management_Nitrous oxide (N_20) kg	0.007	0.003	0.00005	0.01
Manure management CH_4	2.35	0.20	0.0002	2.556
Manure management CH_4 in CO_2e	58.82	5.7	0.0054	63.89
Manure management N_2O in CO_2e	2.17	0.89	0.016	3.078
Total emission in CO_2e.	2766	155.7	0.021	2922

6.3.3 Estimation of emissions associated with maize production

Table 6.7 shows the maize production sub-domains and associated emissions levels. Emission associated with maize production arose from the use of fertiliser for soil nutrient replenishment; soil management which is a natural process linked to soil manipulation during cultivation; and maize residue disintegration as they rot. Maize production associated emissions were mostly Nitrous oxide. Emissions associated with soil nutrients replenishment was estimated at 750kg CO_2e in 2017 with 71%, 17% and 12% arising from manure application, top dress with CAN and basal application of DAP respectively. High levels of CO_2 emissions were associated with organic soil management and residue decomposition. On average every household emitted 12,818 kg of CO_2e associated with maize production activities in 2017. Off the total household emission associated with maize production, 81%, 13% and six percent arose from maize residue decomposition, soil management and soil replenishment, respectively. Maize associated emissions estimated at 5.8kg CO_2e were mostly associated with the natural phenomenon including residue decomposition and outcome of soil manipulation arising from land cultivation.

The use of agricultural residue as a cooking energy source (Egeru et al., 2014) appeared to be a strategic intervention that reduces levels of emission associated with maize residue decomposition. Although, either way, GHG emissions were expected, the use of waste as cooking energy may be considered advantageous to emission reduction efforts with every household mitigating about 2419kg CO_2e through using waste as fuel. Allowing agricultural

Table 6. 7 Households average emissions associated with maize production

	Soil replenishments			Organic soil management emissions (natural process	Maize residue decomposition	Total emissions
	Basal (DAP)	Top-dressing (CAN)	Manure			
	2017 Emissions in kg					
Nitrous oxide (N_2O) Emissions	0.30	0.44	1.78	5.51	34.8	43.01
Emission $N_2O\_CO_2$ Eq.	89.4	130.7	530.3	1641.4	10378	12818
CO_2 Equivalent maize kg^{-1}	0.041	0.06	0.242	0.748	4.723	5.841

waste to decompose in-situ assures soil organic matter, nutrients, and desired soil texture (Sanchez, 2002), however, it allows increased avenues of emissions. Forty grams (0.04kg) and 0.06kg of CO_2 are associated with producing a kilogramme of maize using inorganic fertilisers DAP and CAN respectively, compared to 0.24kg associated with the application of manure. It implies therefore that inorganic production was associated with lower levels of emissions compared to organic farming systems.

6.3.4 Households' emissions associated with cooking and lighting energy

Major pollutants associated with biomass cooking energy and paraffin fossil fuels included carbon dioxide, carbon monoxide (CO), methane, total non-methane organic compounds (TNMOC), and respirable particulate matter (PM) as shown in Table 6.8. Among the biomass and fossil fuel emissions, only carbon dioxide and methane are GHGs as they contribute to global warming (Bailis et al., 2015). Others emissions, including CO, TNMOC, and PM are not associated with climate change although they have detrimental human health impacts (De et al., 2014; Edwards et al., 2015; Marco et al., 2019).

Firewood was observed to have the highest emissions for all the pollutants. The higher levels of emissions arising from firewood use were due to its wide usage among smallholders, the amount utilised and the fact that this energy source is unprocessed and hence have high levels of impurities. Maize wastes utilisation as a cooking energy source came second in emitting higher levels of pollutants. Despite being an unprocessed form of energy source, maize waste had lower levels of emissions attributable to the household's

Table 6. 8 Households' pollutants associated with cooking and lighting energy in western Kenya

	Kerosene	Firewood	Charcoal	Maize cobs	Biomass Cooking emissions	Cooking + lighting
Pollutants		*Average household's emissions (kg) per year*				
CO_2	59.85	6092.2	328.5	164.45	8065.23	8663.7
Carbon monoxide (CO)	5.12	199.8	20.83	56.34	276.98	282.1
Methane (CH_4)	0.09	33.68	0.89	5.09	39.65	39.74
TNMOC	0.064	32.16	1.32	2.62	36.11	36.17
PM_annual	0.06	9.46	0.27	2.62	36.11	124.11
Methane (CH_4) in CO_2e.	2.26	841.93	22.14	127.13	991.21	993.47
Greenhouse emission in CO_2e	600.7	6,934.1	350.7	1,771.7	9,056.5	9657.2

level of utilisation among smallholders and its nature as a result of its growth being less than a year which affected its emission factor value (Chen et al., 2017). The use of charcoal as a cooking source of energy had the least levels of emission. The observed low emission as a result of charcoal usage for cooking was attributable to two factors. The minimal usage of charcoal as a cooking energy source in both amount and proportion of households was associated with its costs, accessibility challenges and preference among users. Secondly, charcoal is a processed wood fuel and hence it has a low emission coefficient at the utilisation level. Annually, the average household's emissions associated with biomass cooking energy was 9.1 tonnes of CO_2 equivalent with the use of firewood, maize waste and charcoal accounting for 77%, 19% and three percent respectively.

Paraffin was mostly used for lighting and its emission levels were low compared to other energy sources. The opportunity for reducing emissions associated with paraffin could be increased through the adoption of cleaner lighting energy sources including electricity and solar panels. Annually, the use of paraffin was linked to the emission of 601kg of CO_2 per household.

Carbon dioxide and methane were the main pollutants contributing to GHG emissions associated with biomass cooking energy among smallholders. Inclusion of lighting emissions to that of biomass increased levels associated with cooking by less than a percentage for both CO_2 and Methane.

6.3.5 Maize-based household total greenhouses emissions in western Kenya

Table 6.9 shows the estimated annual GHG emissions for various sub-domains activities in western Kenya. Key variables that accounted for total households' emissions included GHGs discharges associated with agricultural (maize) production, cooking energy use, livestock husbandry and lighting (kerosene). Maize production emissions were a derivative of a sum of GHGs discharges from anthropogenic soil replenishing interventions (manure, DAP and CAN applications) and natural biological processes including organic soil management and residue decomposition.

Table 6.9 Household annual emissions of GHGs for various agriculture and energy activities in 2017

Emissions	Mean	Std. Dev.	Min	Max
Emission characteristics	*Household's emission levels of CO_2e $kgyr^{-1}$*			
Maize residue decomposition	1641.35	5547.78	0	100378.9
Manure application of farm	530.32	2084.90	0	25568.4
Basal (DAP) inorganic fertiliser	89.41	319.31	0	5386.26
Topdressing (CAN) inorganic fertiliser	130.73	576.08	0	10356.4
Lighting fossil energy (kerosene)	594.41	1077.00	0	9320.64
Livestock management	2921.56	3145.90	0	25870.32
Biomass cooking energy	19129.58	196457.5	0	3835136
Maize production (CO_2e Kg)	12817.52	14654	566.19	133831.6
Totalemissions	24787.31	18655.32	1994.01	160891.8
Per capita total emissions (tonne/kg)	6.57	6.679	0.354	88.4

On average, a household's cooking energy emissions was 19130kg CO_2e. Values associated with households who used other cleaner sources of energy including electricity and LPG were excluded. Kerosene used for lighting contributed about 600kg CO_2e per year. On average, total emissions per adult equivalent was 6.57 tonne CO_2e. Per adult equivalent emissions varied widely with the lowest being below one and the highest above 88 tonnes CO_2e per annum.

The household levels of emission reported in this research were lower than those reported in a study (Druckman & Jackson, 2016) where the households' emissions in the USA were as high as 48 MT CO_2e. Of the total emissions in the USA household, transportation, housing, food, goods and services accounted for 36%, 31%, 18%, and 15% respectively. The average per adult GHGs emissions of 6.57 tonne CO_2e was high compared to levels reported in another study (Hoornweg et al., 2011) which evaluated households' emissions levels for Sri Lanka and some European Cities. The emissions levels reported in western Kenya were higher than those reported for the Sri Lankan Cities and some European Cities e.g. Barcelona. The differences could be attributable to the fact that, unlike the current study which looked at both production and consumption, the other study (Hoornweget al., 2011) only estimated consumption associated discharges. In another study in China (Huang et al., 2018), rural households reported higher direct emissions than their urban counterparts around Beijing.

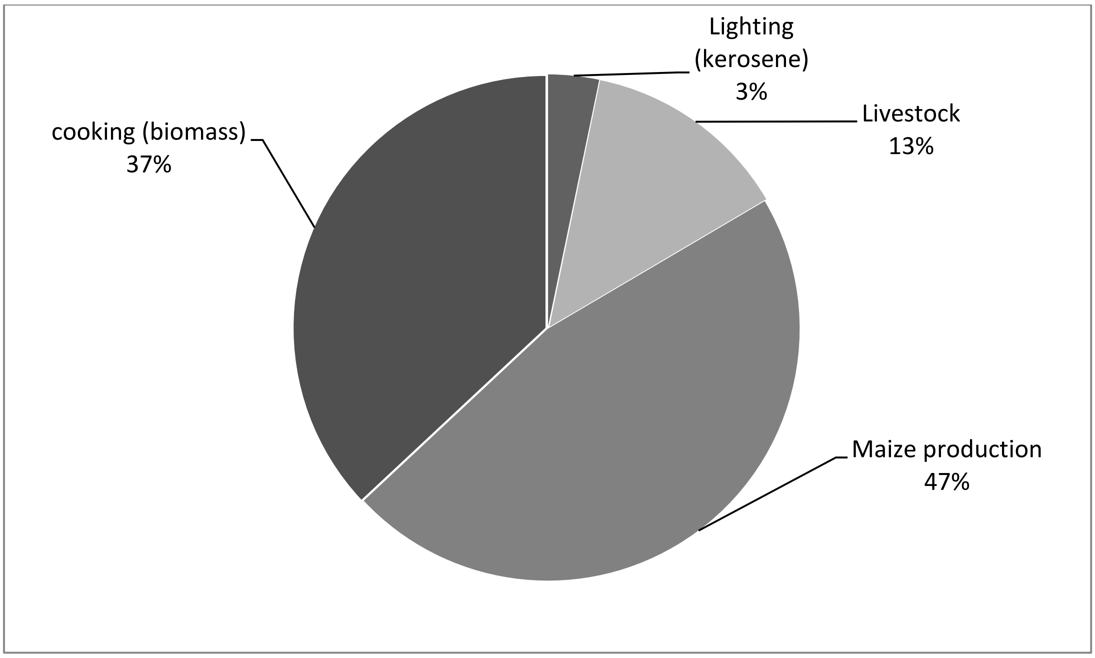

Figure 6.1 Contribution of GHG emissions by various sub-domain activities by agricultural households in western Kenya in 2017

Figure 6.1 shows how various household production and consumption activities contributed to the total emissions by the households. Agricultural production associated GHGs discharges accounted for almost half of total emissions.

6.3.6 Agricultural production emission levels among the sub-counties

Table 6.10 shows the household's emissions associated with livestock management and maize production among cluster sub-counties. A test for differences (ANOVA) showed dissimilarity of sub-counties means for emissions associated with fertiliser usage (basal and top-dressing), organic soil management, maize residue disintegration and maize production. A Benforroni analysis of differences for multiple groups' means showed the presence of significant differences between Bungoma North and Sabatia on emissions associated with fertiliser use. The reported levels of emissions associated with inorganic fertiliser use were significantly higher in Bungoma North compared to Sabatia. Although smallholders in Sabatia were associated with significant ($p<0.05$) low levels of emission in maize production compared to Mt. Elgon and Bungoma, emission per kg of maize produced were significantly ($p< 0.01$) higher compared to all the sub-counties.

The higher emissions levels associated with a unit production of maize in Sabatia were attributed to low-efficiency production. Despite farmers investing in soil nutrient replenishment and allocating land to maize production, very low yields were reported. Some of the reasons for the low yields included the fact that some farmers harvested the crop when it was still green, a quantity they could not ascertain in accounting for total annual yield. Optimization in resource utilisation including fertiliser, manure, and land will enhance efforts for reducing emissions associated with maize production. Soil nutrient replenishment and organic soil management emissions appeared fixed to the number of inputs used while emissions associated with residue management were more dependable on yields.

Analysis of variance outcomes for the emissions associated with cattle ($F= 1.57$, $Prob > F =0.1952$) and goat ($F = 13.5$, $Prob > F =0.2563$) showed no significance differences among sub-counties. The observed emission outcome associated with the ruminants was attributable to the low number of livestock managed by smallholders in all the sub-counties. Emission associated with chicken management was significantly higher in North Bungoma compared to Mt. Elgon.

Table 6. 10 Annual households CO_2 emissions by activities in various Sub-Counties

Households activities	Bumula (B)	Elgon (E)	North (N)	Sabatia (S)	F	Prob > F	Bonferroni P-values	Sub-counties differences
	Annual CO_2 Equivalent emissions in Kg							
Basal (DAP) emissions	93.75	82.92	154.24	28.24	2.68	0.0468	P< 0.05	S< N
Topdressing (CAN) emissions	120.62	108.6	144	43.56	3.45	0.0167	P< 0.05	S< N, S<B
Manure application on Maize	178.4	15.4	147.8	169.2	2.35	0.0725	n/s	N/A
Organic Soil management	1377.23	1716	2903.9	512.53	3.20	0.0235	P< 0.05	S< N
Maize residue disintegration	9662	14773	10053	6887	6.46	0.0003	P< 0.05	B< E, N<E, S< E
Maize production	12058	16751	13179	8254	5.76	0.0007	P< 0.05	S< E, S< N
Unit maize production (kg)	12.2	14.0	11.47	32.9	20.52	0.0000	P< 0.01	B< S, N<S, E< S
Cattle Enteric CO2 Eq.	1758.6	2146.8	1803.4	1550	1.57	0.1952	n/s	N/A
Cattle Excretion	136.7	166.8	140.1	120.5	1.57	0.1952	n/s	N/A
Cattle manure management	58.83	78.7	66.1	56.9	1.57	0.1952	n/s	N/A
Goat Enteric CO2 Eq.	125.3	196.3	115.1	68.2	1.35	0.2563	n/s	N/A
Goat Excretion CO2 Eq.	75.2	117.8	118	40.9	1.35	0.2563	n/s	N/A
Goat manure management	5.01	7.84	4.60	2.72	1.35	0.2563	n/s	N/A
Chicken manure management	0.018	0.01	0.029	0.022	4.14	0.0066	P< 0.05	E< N

NB: n/s Not significant; N/A Not applicable

6.3.7 Proportion of emissions associated with various activities among sub-counties

Figure 6.2 shows the proportion of GHG emissions for various household activities in the sub-counties. Maize production contributed 47% of total emissions in the entire sampled area. Biomass cooking energy utilisation accounted for 37%, while livestock and lighting (kerosene) was 13% and three percent respectively. Identical patterns were observed in all the sub-counties where maize production accounted for most emissions while paraffin lighting energy contributed the least. Despite the differences in the socio-economic characteristics of farmers in the sub-counties, the patterns of emissions associated with various activities were identical across the sub-counties. However, what differed across the sub-counties is the proportion of emissions by various households' activities. Households' intensities in undertaking various activities contributed to the differences in the proportion of emission by activity. Larger farms allocated to maize production in North Bungoma exacerbated emissions from maize production.

Adoption of other lighting sources apart from paraffin in both Mt. Elgon and Bumula reduced the proportion of emissions associated with lighting. Maize farming in smaller farms coupled with poor accessibility to biomass energy in Sabatia magnified the proportion of emissions arising from livestock management.

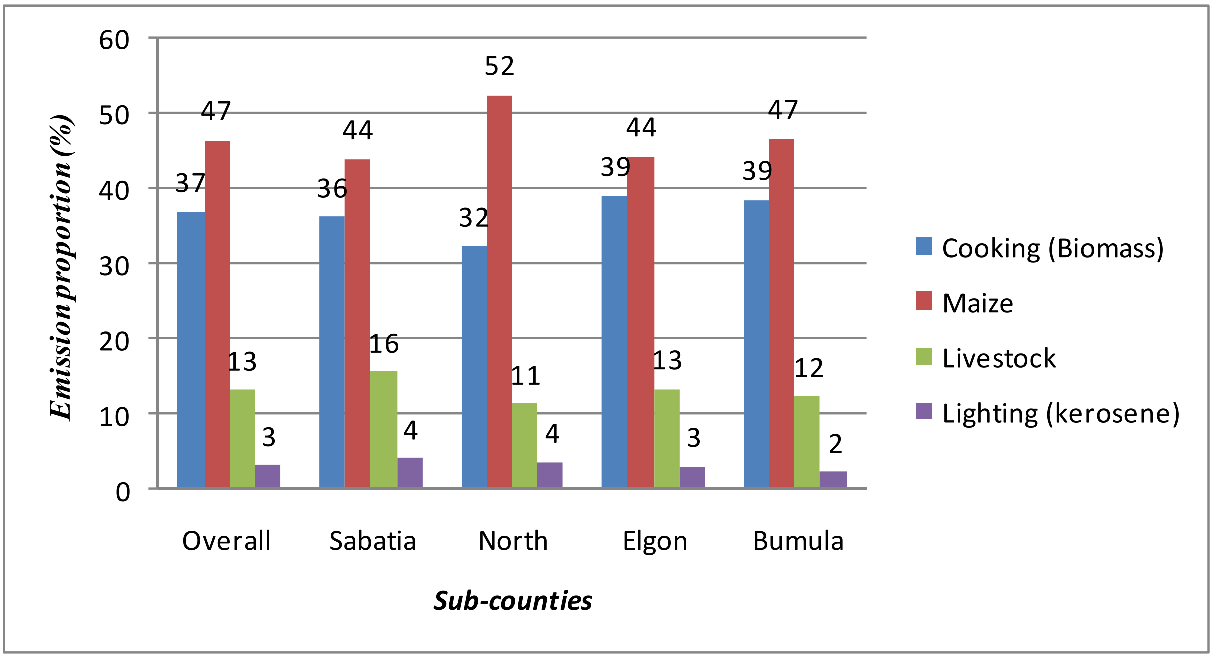

Figure 6. 2 Proportion of GHG emissions by households' activities in the sub-counties

6.3.8 Determinants of GHG emissions among smallholders in western Kenya

Table 6.11 shows the results of the multiple regression analysis on determinants of emissions among smallholders in western Kenya. The regression model showed Prob. (F) to be significant (P=0.000), R-squared to be 57% and adjusted R-squared to 53%.

Per adult equivalent, GHGs' emissions were positively and significantly (P<0.01) influenced by household's maize yields achievement and income (consumption expenditure). Geographical location differences, especially in Bungoma North compared to Sabatia showed significant levels of variations in GHGs emissions. Per adult equivalent, GHGs' emissions were negatively and significantly (P<0.01) influenced by the number of members in a household. The number of trees propagated and managed by a household.

Consistent with other studies (Druckman & Jackson, 2016; Li et al., 2016) income was significant in influencing the GHGs emissions. Unlike other environmental input-output models (Wiedmann, 2009) that estimate emissions based on consumption of product's group's final demand (Minx et al., 2009) this study approach was from the processes of subsistence production and consumption. Generally, the current study could be considered critical in supplementing the input-output model weakness of insufficiency in data (Lensen et al., 2013) and broadness (Minx et al., 2009). Process of subsistence agricultural and energy production and consumption in households of western Kenya and their resultant emissions of GHG were influenced by income and mirrors outcomes of the input-output model systems.

Maize yields were a production associated activity that was influenced by levels of investment and with subsequent effects on lifestyle /expenditure (Weiler et al., 2014) and more activities. The results are consistent with other studies that have associated GHG emissions with increased income (Druckman & Jackson, 2016). Increased production of the agricultural commodity (maize) was coupled by the process that enhanced GHGs emissions. These processes may include own input linked to anthropogenic nutrient replenishing and natural biological procedures, and cross associated energy production and consumption activities including high use of biomass energy. In this regard, therefore the results of the current study deviated with other life-cycle assessment studies that associated inefficiencies and low yields to higher per-unit emissions (Henderson et al., 2016; Sapkota et al., 2018; Udo et al., 2016). Consequently, the GHGs emissions reduction recommendation associated with the life-cycle assessment of enhanced intensification and technical efficiency (Henderson et al., 2016; Udo et al., 2016) may not be viable for the case of western Kenya. However, with the low technical efficiency (Henderson et al., 2016), food insecurity (Tittonell & Giller, 2013; Udo et al., 2016) and prevailing levels of income poverty (Bigsten et al., 2016),

Table 6. 11 Results of linear regression of determinants of emissions per adult equivalent

Household characteristics	Coef.	Std. Err.	t	P>t	[95%Conf.Interval]	
Household head Characteristic						
Age of household head	-11.22	27.62	-0.41	0.69	-65.59	43.16
Gender of household head	633.08	719.34	0.88	0.38	-782.94	2049.11
Farming experience	34.89	29.55	1.18	0.24	-23.29	93.06
Formal employment	-1708.57	968.13	-1.76	0.08	-3614.33	197.19
Formal education achievement	127.19	93.27	1.36	0.17	-56.42	310.80
Household characteristics						
Household size	-817.18	141.81	-5.76	0.00	-1096.33	-538.02
Enjoying credit facilities	852.64	1103.91	0.77	0.44	-1320.41	3025.69
Hours of activities daily	0.04	0.07	0.58	0.56	-0.10	0.19
Per capita expenditure	12.87	7.30	1.76	0.08	-1.49	27.24
Total land owned	-261.57	121.80	-2.15	0.03	-501.33	-21.81
Agricultural characteristics						
Number of crops' enterprises	-144.76	357.49	-0.40	0.69	-848.48	558.97
Maize production sufficiency	-1.79	13.94	-0.13	0.90	-29.23	25.66
No. tropical livestock unit	1718.67	195.24	8.80	0.00	1334.33	2103.00
Farmer group membership	-595.45	1054.30	-0.56	0.57	-2670.84	1479.94
Maize yield achieved	0.84	0.07	12.14	0.00	0.71	0.98
Energy characteristics						
Solar installation	-908.46	636.09	-1.43	0.15	-2160.61	343.69
Improved cooking stoves	-301.02	633.57	-0.48	0.64	-1548.20	946.16
No. of cooking energy sources	507.24	331.48	1.53	0.13	-145.29	1159.76
Distance covered for firewood	535.59	268.40	2.00	0.05	7.25	1063.93
Own farm firewood sufficiency	735.84	655.13	1.12	0.26	-553.78	2025.45
Bumula	482.30	970.56	0.50	0.62	-1428.26	2392.85
North	2781.21	898.89	3.09	0.00	1011.73	4550.68
Elgon	985.36	936.10	1.05	0.29	-857.37	2828.00
_cons	1909.57	2238.21	0.85	0.39	-2496.36	6315.50

F (23, 279)	16.13

Prob (F)	0.0000
R-squared	0.5708
Adj R-squared	0.5354
Root MSE	4694.1

boosting production could be solely through intensification as access to land for agriculture is also limited (Place et al., 2016). Increased productivity and enhanced income targeted for placing households above the poverty levels result in benign GHGs emission levels (Hubacek et al., 2017) but excessive consumption leads to threatening levels of discharges.

The household size was negatively and significant ($P<0.01$) in influencing per AE GHG emissions. The lower per AE GHG emissions associated with larger households and vice-versa points to the scale of operations in terms of environmental discharges. This outcome contradicts observations that linked household size to increase per-unit emissions (Creutziga et al., 2015). The number of trees planted by a household weakly ($P = 0.053$) influenced the per AE GHG emissions.

Locational factors influenced the levels of per AE GHG emissions. Shifting to Bungoma North from Sabatia positively and significantly ($P=0.003$) affected the per AE emissions. Weakly significant ($P = 0.073$) per AE emissions were observed for Mt. Elgon compared to Sabatia. The observed per adult equivalent emissions levels differences in location (clusters) were consistency with results for entire farm emissions quantification in the same region (Prado et al., 2013) which showed emissions differences among sites. Differences in farm typologies were associated with farm emissions differences by agro-ecological zones. Different rural clusters as defined by agro-ecological zones, socio-economic factors and vicinity to public forests influenced the individual's lifestyle and consequently emission levels. The observation was consistent with Pandey and Agrawal (2014) who reported GHG emission differences due to geographical regions and environmental conditions. Geographical regions' differences in per capital GHG emissions were also associated with carbon intensity and income levels (Huang et al., 2018; Li et al., 2016).

6.4 Conclusion

The incorporation of survey data on agricultural production and energy consumption, and emission coefficient information have allowed for estimation of households' carbon footprint.

Emissions contributed by agricultural production activities were higher than those associated with energy utilisation. Livestock husbandry associated emissions including enteric and manure management accounted for most of the GHG emissions at households. Agricultural production emissions were mostly Methane and Nitrous Oxide. Carbon dioxide accounted for most of the GHG emissions from energy utilisation. Determinants of per adult equivalent GHGs emissions were levels of consumption expenditure, household size, maize yield achievements and geographical location. Efforts to reduce household GHGs emissions need to address the adoption of cleaner cooking and lighting energy, efficiency in livestock production and use of inorganic farming inputs for crop production.

Emissions contributing to greenhouse gas atmospheric accumulation notwithstanding, it is important to reduce pollution that affects the health of household members (Ezzati & Kammen, 2001) thereby indirect affecting agricultural production and farming community welfare.

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CHAPTER SEVEN

GENERAL DISCUSSION, CONCLUSION AND RECOMENDATIONS

Abstract

Addressing smallholders' food security and their poverty status continue being an insurmountable challenge due to the linkages between agricultural food production, their socio-economic characteristics, the agro-ecology and the ability of the environment and the farming system to tackle the welfare issues as postulated by the 17 sustainable development goals. Moreover, the increasing population has continued aggravating the smallholding resources' availability, despite increasing demands for more food and diverse products including bio-energy. Furthermore, the impacts of climate change have affected the farming system, necessitating more demands in greenhouse gas removal. While most researchers solely focus on socio-economic characteristics of farmers in their attempts to mitigate challenges in agriculture, more inclusions approach may be required. In this study, a nexus approach between cooking energy, food production and greenhouse gas emissions are assessed. Having addressed the smallholders' socio-economic characteristics, and how the influence cooking energy choice, trade-off between cooking energy and food production, and greenhouse gas emission in previous chapters, in this chapter, the nexus between biomass cooking energy, food production and greenhouse gases emissions and removal is illustrated. Outcomes of a triangulation of existing related information and results observed in this research are presented. Biomass cooking energy demands and utilisation affected the agro-ecology through vegetation denudations, soil resources' degradation, loss of biodiversity and pollinators', and effects on aquaculture production. The social components of agriculture were affected by cooking energy utilisation pollutants associated ailments and production resources scarcity. Ailments associated to pollutants were six and nine percent, and six and eight percent for children below five years and persons above 5 years in Vihiga and Bungoma Counties respectively. Household limited production resources including land and capital were strained in allocation for food production as they had to be shared with cooking energy demands. Synergy was observed between the food production and cooking energy for labour and other operations systems including yields. The numbers of trees managed by smallholders were able to meet firewood demands in most cases (58%); and offset emissions associated with biomass cooking energy in Sabatia, Bungoma North and Bumula. Both cooking energy and maize production associated emissions were off-set by trees carbon sequestrations capacities in Bumula and Bungoma North. Smallholding in western Kenya was observed to be a complex farming complex

involved in food and biomass cooking energy production, offering other ecology functions of trees and climate change mitigations.

7.1 General Discussion

In understanding the complex relationship between ecological systems and the high demands on the ecosystems' functions presented by the population pressure, changes in lifestyles and industrialisation, and against the growing quest for sustainability, a nexus approach has been recommended (Shah et al., 2020). The nexus approach is a new paradigm that comprehensively identifies interactions between multiple systems to produce a combined effect greater than the sum of their separate effects, with most studies already reported addressing water-energy-food-environment components (FAO, 2014; Kevser et al., 2022; Shah et al., 2020). In this chapter, the study attempts to describe the relationship between biomass cooking energy, food production, and greenhouse gas emissions. Despite the relationship being complex, the review undertakes a simple analysis with its key components being the agro-ecosystem and social system. The review was overly simplified and, in this regard, considered staple (maize) production as the only food production process and assumes no cash crop was produced. Despite tree planting, a response to biomass cooking energy demand being an agricultural activity, as it takes place in the same space as the case with maize farming; it was considered a unique operation with its carbon sequestration function of key importance.

In Chapter 3, the socio-economic characteristics of smallholders were presented, including those associated with the household head, the households, and the household's environment. Differences in socio-economic characteristics by sub-counties were reviewed to verify heterogeneity presented by the agro-ecological. Households' utilisation of various cooking energy choices by key meals, including lunch, supper, and breakfast, and duration used were discussed. Trends in food and cooking energy sufficiency status by the months of the year have been shown. Smallholders' food sufficiency situations and respective intervention strategies in addressing the challenges of improving household food security were described.

In Chapter 4, socio-economic factors influencing preference for various energy choices by key meals have been elucidated. High dependency on biomass cooking energy sources was illustrated for all the key meal types, with most households strongly preferring firewood for cooking in comparison to all others. Other largely preferred choices apart from firewood, including charcoal, twigs, and agricultural waste, are biomass in nature that drives deforestation and denudation of the biomass resource. Denudation of the biomass resource has repercussions to the agro-ecosystem and its capability to offer ecosystem services (Christen & Dalgaard, 2013). Moreover, the biomass resource is critical for carbon dioxide removal from the atmosphere. The combustion of biomass through its use in cooking leads to greenhouse gas emissions and hence climate change (Pachauri et al., 2021).

To ensure the availability of biomass cooking fuel, smallholders have adopted tree planting as an agricultural activity. While tree planting responds to failure to shift to cleaner energy choices, several advantages have been associated with trees. By planting trees, farmers increase the biomass resources available in an agro-ecosystem and also globally, thereby improving the ecological welfare (Lin et al., 2022; Rosen et al., 2016). The net effects of tree planting against utilisation of the biomass resource depend on the balance of biomass increase of planted trees to that which was removed for cooking. Some of the advantages of the increased biomass include ecological offsetting (Fassina et al., 2022) of biomass removal and Carbon dioxide sequestration.

In Chapter 6, greenhouse gas emissions by various smallholders' activities, including biomass combustion during cooking,were evaluated. The ability of increased biomass resources arising from tree planting to off-setting greenhouse gas emissions by cooking energy and agricultural production is essential. Although the global trade in Carbon Credits is premised on increased emissions elsewhere, the local environment needs to be evaluated to bring every actor, including smallholders, abound climate mitigation strategies.

7.1.1 Biomass cooking energy and the smallholding agroecology nexus

Generally, it was observed that households largely depended on biomass sources of cooking energy, including firewood, twigs, agricultural crop wastes, charcoal, and sawdust. Biomass energy sources were derived from the agro-ecosystem that was also critical in supporting agriculture and, by extension, food production. Figure 7.1 shows the proportion of households using different cooking energy sources in the sampled sub-counties. Only nine and five percent of households considered the use of LPG and kerosene, respectively, the only non-biomass fuels as their cooking energy sources. Charcoal is a processed product that is sourced from biomass. While it was considered a cleaner energy source due to its lower emissions of pollutants, the process of its production has been observed to have wider negative repercussions on vegetation, the environment, agriculture, and human health (Eniola, 2021).

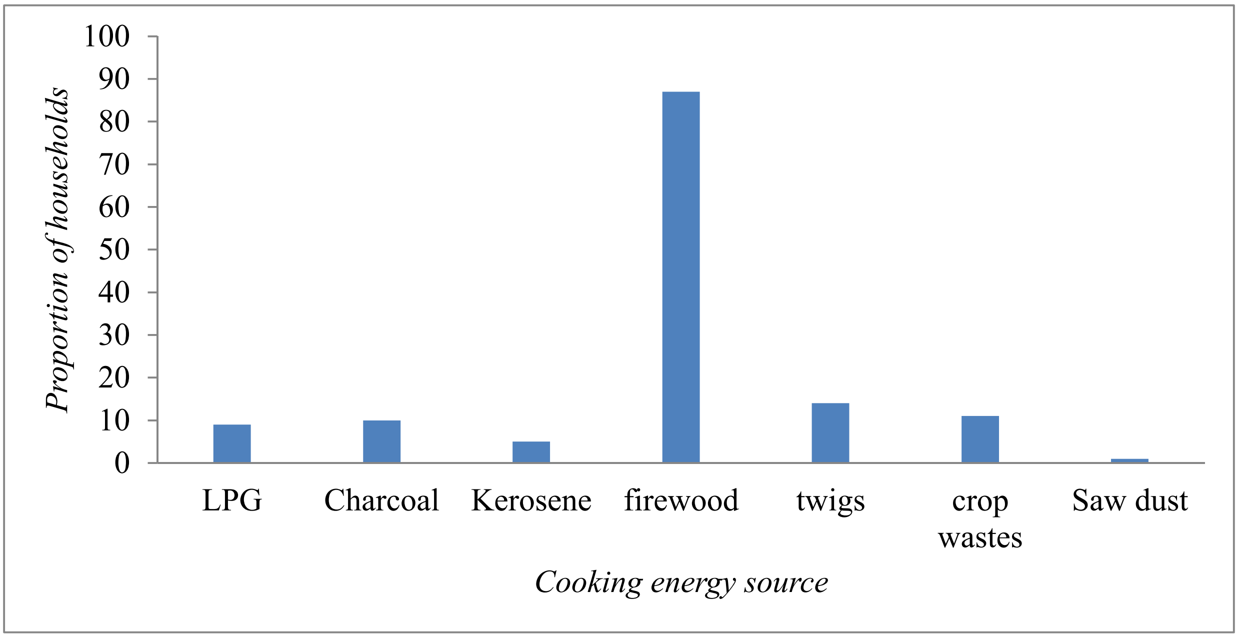

Figure 7. 1: Proportion of households using various cooking energy sources for all the meal types in the sampled sub-counties.

On its part, sawdust is a by-product of alternate extractive use of trees beyond cooking fuel. The recycling of the timber-industry by-product for use as an energy source could be considered as efficient in biomass utilisation. However, sawdust has other potential uses, including improving soil quality and mulching in agriculture and for particleboard and wood pulp in the construction industry. The high proportion of households relying on biomass energy sources for cooking implied that the extraction of vegetation was quite high. The vegetation removal happened on both the agro-ecosystems and the natural ecosystem, either the forests or rangelands.

Table 7.1 shows the estimated levels of vegetative removal to respond to biomass cooking energy demand among the sampled households. Every household in the sampled area required about 3.6 tonnes and 1.2 tonnes of biomass to meet their firewood and charcoal annual demands, respectively. Although the lowest amount of firewood utilisation was reported among households in Bumula compared to other sub-counties, its charcoal utilisation levels had a more harmful effect on the biomass resource. On average, every household in Bumula used 58, 67, and 77 percent more charcoal than levels in Mt. Elgon, Sabatia, and North Bungoma, respectively, consequently leading to high deforestation in charcoal production. The highest level of biomass resource utilisation in response to

Table 7. 1: Firewood and charcoal utilisation, and annual biomass removal among sub-counties

	Households' average annual firewood weight usage (kg)	Households' average daily charcoal usage (kg)	Average Annual Biomass (kg) associated with charcoal production at 10% conversion	Annual biomass (kg) removal
Overall	3594	0.352	1181.2	4719.0
Bumula	2960.5	0.78	2710.8	5636.5
Mt. Elgon	5318.5	0.31	1135.3	6656.7
North Bungoma	2995.9	0.168	614.7	3610.6
Sabatia	3161.5	0.24	885	4383.5

All charcoal utilized was assumed to be from traditional earthen kiln produced where yields from wood to charcoal were10% (Njenga et al., 2021)

biomass energy demand was reported in Mt. Elgon, with every household estimated to utilise 6657kg annually. The level of annual biomass utilisation in Mt. Elgon was 15%, 46%, and 34% higher than those utilised in Bumula, North Bungoma, and Sabatia, respectively. The impacts of the reported biomass removal in response to cooking energy demand had a more devastating effect on the environment when the entire region's population was considered. Table 7.2 shows the entire sub-counties estimated biomass resource required to meet the population's energy demand.

Households in Bungoma North, Bumula, and Mt. Elgon sub-counties accounted for 24% of the total numbers in Bungoma, and those in Sabatia represented 22% of the total in Vihiga based on the Kenya Demographic Survey 2019 (KNBS, 2019). Overall in the sub-counties, the proportions of those utilising firewood and charcoal have been shown in the table as reported (KNBS, 2019). The incorporation of the households' average levels of firewood and charcoal annual usage (2017) and the data on the total numbers of households and proportion using each of the energy sources provided the estimated values for biomass utilisation in each of the sampled sub-county. Overall the biomass resource utilised in response to high usage of biomass energy sources was 126.2, 82.7, 73.2, and 67.9 thousand of tonnes in Bumula, Sabatia, Bungoma North, and Mt. Elgon, respectively. A total of 350 thousand tonnes of

Table 7. 2: Biomass resources demand associated with firewood and charcoal for the entire population in the sampled sub-counties

Sub-county	County	Estimated household numbers per sub-county	Proportion of households in the county	Proportion using biomass energy		Biomass demand ('000 tonnes)		Cooking energy demand '000 tonne	Biomass in 000' m^3	Biomass harvest in hectares
				Firewood	Charcoal	Firewood	Charcoal	Biomass	Biomass	Biomass
Bumula	Bungoma	44922	13	89.9	5.4	119.6	6.58	126.18	308	4400
Bungoma North	Bungoma	24940	7	89.8	4.3	67.2	0.66	67.86	166	2400
Mt. Elgon	Bungoma	15230	4	88.9	7.1	72	1.23	73.23	179	2600
Sabatia	Vihiga	31391	22	80.9	8.6	80.3	2.39	82.69	202	2900
Sampled area		116483	11.5	87.4	6.4	339.1	10.86	349.96	854	12200

NB: Specific density =0.41gcm^{-3} and Yield per ha = 70m^{3}ha^{-1}yr^{-1} (Oballa et al., 2010)

Source: Authors data, KNBS (2019) and Oballa et al. (2010)

biomass resource was harvested to meet biomass cooking energy demand in 2017 in the four sub-counties. It is important to note that the households' number in the sampled sub-counties only accounted for about a percent (0.97%) of the total number of Kenya's households in 2019 (KNBS, 2019). The biomass resource harvested corresponded to 854000m3 biomass when its density was considered as 0.41g cm^{-3}as in the case of Eucalyptus Saligna (Oballa et al., 2010). A forest stand resource of 12200 ha was harvested to meet the biomass demand if biomass increment of $70m^3ha^{-1}yr^{-1}$ was assummed (Carson et al., 2012; Oballa et al., 2010).

While the biomass demand read high against the forest resource, biomass resource has been observed to be diverse (MEMD, 2013; Openshaw, 2011). For example, although Uganda extracted about 44 million tonnes of biomass annually, the country's assessment of the biomass supply concluded supply exceeded demand; hence better technologies were recommended instead of restricting use (MEMD, 2013). Kenya's forest area was 17.1 million ha, compared to Uganda's at 4.2 million ha (IPCC, 2016). The biomass resource acreage in Uganda was 17.2 million ha on private land, excluding national parks and forest reserves, with biomass stock estimated at 284 million tonnes (MEMD, 2013). Kenya's demand and supply of wood products in 2013 indicated that firewood and charcoal supply stood at 13,654,022m^3 and 7,358,717m^3 while demand stood at 18,702,748m^3 and 16,325,810m^3 respectively (Oduor et al., 2020). In this regard,a demand deficit of 37 and 122 percent was observed for firewood and charcoal, respectively. A review of biomass use and supply in response to an alarm by five international agencies on depleted biomass resources to meet demand in developing countries showed the growth and yield of aboveground woody biomass had been underestimated due to the use of conservative methodology and data by FAO (Openshaw, 2011).

The biomass resource harvested was observed to be influenced by, among others, three factors, including the per-household levels of utilisation, the number of people relying on biomass energy, and the type of energy (either firewood or charcoal) used. Despite per-household firewood utilisation being the lowest at 2961 kg per annum (see Table 7.1) among the sampled sub-counties, the high proportion of households in Bumula using firewood and its large counts of households was attributable to the 120 thousand tonnes of biomass resource harvested. On the other hand, although Mt. Elgon had the highest per-household firewood utilisation rate of 5319 kg (see Table 7.1), its' low households' count was attributed to the estimated low biomass resource harvested of 72 thousand tonnes. The choice of either firewood or charcoal also affected the biomass resource harvest as although the latter may have been associated with the yielding of higher energy in cooking per unit (Otieno et al., 2022), its' processing efficiency was important in determining biomass resource requirement. Adoption of efficient kiln technology can improve the conversion rate of charcoal from wood to 44% from the traditional earth mould, which only yields 10% (Njenga et al., 2021).

The reported high vegetation removal on agricultural land had detrimental effects in terms of soil conditions and fertility, soil and water erosion, biodiversity loss and reduction of carbon removal potential of the land. Deforestation leads to alteration of the cycles of elements controlling the primary production of ecosystems including carbon, nitrogen and hydrogen cycles. Removal of vegetation in farmland affected the soil conditions by reducing on the organic matter composition (Acin-Carrera et al., 2013; Prout et al., 2020). Specifically organic matter composition effects on soil conditions include the soil organic carbon (SOC)/clay ratio (Prout et al., 2020), bulk density, aggregate stability and water-holding capacity (Acin-Carrera et al., 2013). Organic matter improves soils' physical, chemical and biological functions that are critical for agricultural production, soil conservation and management (Gurmu, 2019). Soil is a complex system with key components generally being mineral (averaging about 45%), organic matter (ranging from 1 to 6%), water (between 20-30%) and air (between 20 and 30%). Although of low proportion among soils' key components, organic matter functioning in terms of soil health, its conservation and management, and its agricultural potential is critical (Zhang et al., 2022).

Soils' biological resource is mostly presented by microorganisms' diversity which increases soil aggregate stability, water infiltration and holding capacity. Greater amounts of nutrients including Nitrogen, Phosphorus and Sulphur are largely cycled from organic forms into those that are inorganic and plant available (Zhang et al., 2022). Organic matter contain sites of negative charges that attract and hold positively charged ions including those of Calcium, Potassium, Magnesium, and Ammonium-Nitrogen. Organic matter affects the soil structure which increases water infiltration and soils ability to absorb and hold water. The water holding capacity of soil helps plants manage water moisture through water deficit periods. Moreover water penetrability potential reduces soil erosion thereby ensuring its availability and its nutrient quality in the agricultural landscape.

Vegetation removal on both natural biomes and agricultural landscape exposes the soil to both agents of erosion including soil and water (Aviles et al., 2020). Vegetation intercepts rain, reducing its energy and prevents splash erosion. It also slows runoff, reduces sheet erosion, and anchors and reinforces the soil with its root system. Surface water runoff from vegetated areas is much less than that from bare soil due to a combination of surface roughness, infiltration, and interception. Extensive and high rates of soil erosion that have been reported to range as high as between 43 to 90 tons/ha/yr recorded in western Kenya has led to diminished food production and security (deGraffenried & Shepherd, 2009). The erosion in this region has been associated with farmlands (above 50%), grass and shrubs land (10%) and forests (16%) with the least being built environment (Kogo et al., 2020). High rates of nutrients release into the rivers and other water bodies are prevalent (Onyando et al., 2016). Extremely high levels of sediments (turbidities as high as 6000 NTU) prevails with the levels increasing over time (Dutton et al., 2018). Water bodies in this area have been observed to be highly polluted with elements including coliforms, turbidity, Mn, Fe and Cu levels found to be higher than the WHO maximum limits for human drinking water (Tenge et al., 2015). Both the surface and sub-surface water has been observed to be highly contaminated for human consumption (Adika et al., 2018; Gomes da Silva et al., 2020).

Analysis of vegetation loss in western Kenya showed the last three decades of the 20th Century to have reported a decline of wooded grassland from 51 to 11% (Waswa et al., 2013). Despite inaccessibility of literature showing changes in the last two decades, the rise in population, land pressure and higher demand of biomass fuel is expected to have had a devastating impact on the remaining vegetation biome and its ability to regenerate. Vegetation removal contributed to soil erosion and hence land degradation estimated to cost Kenya about US$1.3 billion USD annually and the consequent annual maize yield loss of about US$270 million (Mulinge et al., 2016) in each year between 2001 and 2009. Distinct variations on soil properties were observed in terms of cations, anions and silts, high prevalence of strong acidic soils (94% of all farms), and high soils organic matter (SOM) below the critical 2% in 55% of farms (Waswa et al., 2013). The net effect of the soil loss is its suspension on the rivers and later deposition in Lake Victoria. Through the nutrient enrichment from the surrounding catchment area, the lake has been able to sustain water hyacinth invasion (Otieno et al., 2021). With the invasive species affecting the lakes blue economy including transportation, fish resource and water utilisation. Moreover decline in both the aquatic microphytes and macrophytes leading to reduced water fauna (Achieng et al., 2021) and consequently decreasing the potential for fish farming (Tumwesigye et al., 2020) among all the water bodies in the region.

With most of the agricultural households relying on unimproved surface and groundwater (KNBS, 2019) the water quality has repercussion to the households' health status, costs implications in water quality improvement and accessing clean water. Consumption of pathogen contaminated drinking water leads to a number of diseases including cholera, typhoid, dysentery, hepatitis A, salmonella, diarrhoea, Escherichia Coli (E. coli) and giardia (Karen et al., 2023). Between 2014 and 2019 some locations in western Kenya reported contaminated water diseases' burden of above the national mean (Haushofer et al., 2021; Mulatya & Ochieng, 2020). The cost implication of consumption of contaminated water and food in Kenya was estimated at Kenya Shillings (KES) 27 billion annually (WSP, 2012) which was equivalent at per capita of US$8 and a 0.9% of the GDP. The cost was associated to treatment access time (8%), premature deaths (75%), health care (15%) and loss in productivity (1%).

In western Kenya, accelerated rate of flora biomass loss has been reported even in protected areas in the last two decades (Osewe et al., 2022). For example, in Kakamega Forest an estimated 827 ha of forest cover were lost, with the 2000-2010 period losing 147 ha of the cover while the 2010-2020 accounted for 680ha of the loss. The forest cover loss and landscape pattern alterations changed the dynamics of species interaction within ecological communities. Fragmented habitats adversely affected the ecosystem's ability to recover the loss of endemic species, which are at risk of extinction. Forest or biomes cover loss and depletion poses a major risk to animals, both vertebrate and invertebrates by restricting their movements, changing their normal behaviours, denying them food, habitat and water access consequently resulting to their population reduction and even local extinction (Gudka, 2020). Evaluation of impacts of deforestation and fauna habitat loss on agriculture in Kenya however has been complicated by other coinciding factors that have been presented including climate change, use of pesticides and invading species (Nyangena et al., 2020) that also affect the sector's production.

Destruction of the plant biodiversity within and around crop fields and resultant habitant loss of invertebrates and vertebrates have devastating effects on pollinators (Giannini et al., 2015). The flora and fauna within the agro-ecosystem provides genetic resources for food and agriculture hence constituting the biological basis for food security and support for human livelihood (Muigua, 2017). The fauna mostly involved in terrestrial pollination include the birds, bats and insects which are pivotal in production for 80 percent of all flowering plants, 35 percent of the world's crop production and increasing yields for 87 of the major food crops (Aizen et al., 2009; Marcello et al., 2009). Within the agro-ecosystem the diversity of crops systems supported by pollinators include orchard, horticultural and forage production, spices, pulses, cereals, roots and fibre crops (Nicholls & Altieri, 2013). Exploitation of biological resources for energy presents a complex challenge in regards to the genetic resource attributable to existing gaps in research, management, regulation and policing necessitating interventions (Muigua, 2017). Despite the challenges associated with the succinct valuation of the genetic resources due to complex interlinkage within the biological systems and the prevailing scientific knowledge gaps (Gallai & Vaissière, 2009), the loss are predicted to have devastating effects on the ecosystems.

7.1.2 Cooking biomass energy, pollution and household members' welfare

Biomass cooking energy and health concerns in western Kenya

Researchers have attributed biomass cooking energy to indoor pollution, especially the emissions of particulate matter with a diameter of at most 2.5micrometer (Prasad et al., 2012). Globally the use of biomass cooking energy has been associated with at least 3.8 million deaths every year (Shilenge et al., 2022) with about 99% of these occurring in developing countries (Prasad et al., 2012). The use of biomass cooking fuel accounts for at least 6% of global burden of disease (Mishra, 2003). Prasad et al. (2012) presented a comprehensive review associating various pollutants and biomass fuels with various diseases. Pollutants emitted by biomass fuels were highlighted to include small solid particles, carbon monoxide, polyorganic andpolyaromatic hydrocarbons, and formaldehyde. The strength of the association between biomass fuel and various diseases varied for acute respiratory infections (ALRI), chronic obstructive pulmonarydisease (COPD), lung cancer, pulmonary tuberculosis (TB), asthma, and interstitial lung disease (ILD). The World Health Organisation (WHO) has associated 12%, 12%, 44%, 22%, 23% and 11% of death due to ischaemic heart diseases, stroke, pneumonia deaths in children less than 5 years, pneumonia death in adults, chronic obstructive pulmonary disease and lung cancer, respectively to indoor air pollution exposure (Prasad et al., 2012). Other health issues associated with household air pollution include low birth weight, tuberculosis, and cataract, nasopharyngeal and laryngeal cancers.

Table 7.3 shows the diseases associated with biomass cooking fuels that were reported in hospitals by counties for 2020 (KNBS, 2021). The data presented were for the entire country, and figures were reported in Bungoma and Vihiga. Also included in the list are cases of confirmed and suspected Malaria, and upper respiratory tract infections. It has to be noted that the incidence of the reported health issues werecaused or exacerbated by use of biomass cooking energy. Out of the 78 diseases conditions reported in Kenya hospital in 2020, nine (accounting to 12%) of ailments were considered to be associated with indoor pollutions resulting from biomass cooking fuel. Among ailments associated with children below five years included the lower respiratory tract infection and severe pneumonia. The national proportion of ailments associated with biomass cooking fuel was high at 15% compared to six and nine percent recorded in Bungoma and Vihiga counties respectively. Other diseases

Table 7. 3: Hospital visitation by patients in 2020 for the country and the two sampled counties

	Diseases occurrence for children below 5 years in 2020						Diseases occurrencefor persons above 5 years in 2020					
	Country (000)	ratio (%) of ailment	Bungoma ('000)	ratio (%) of ailment	Vihiga ('000)	ratio (%) of ailment	Country ('000)	ratio (%) of ailment	Bungoma ('000)	ratio (%) of ailment	Vihiga ('000)	ratio (%) of ailment
Asthma	72.9	0.6	1.0	0.25	0.3	0.3	561.2	1.42	9.3	0.91	3.6	0.83
Candio-vascular	3.0	0.0	0.8	0.2	0.0	0.0	57.9	0.15	2920	0.29	0.7	0.17
Burns	93.3	0.7	2.5	0.6	0.7	0.7	115.3	0.29	973	0.10	2.4	0.55
Eye infection	254.4	2.0	4.7	1.2	0.9	0.9	625.4	1.59	14.2	1.39	3.5	0.82
LRTI	107.2	0.9	1.6	0.4	1.0	1.0	-	-	-	-	-	-
ODRS	694.1	5.5	10.2	2.6	5.8	5.7	1893.5	4.81	14.7	1.44	16.1	3.72
Pneumonia	694.2	5.5	1.1	0.3	0.1	0.1	1056	2.68	20.0	1.96	8.1	1.88
Severe pneumonia	11.1	0.1	0.2	0.1	0.00	0.0	-	-	-	-	-	-
Presumed tuberculosis	5.3	0.0	0.2	0.1	0.00	0.0	-	-	0.3	0.03	130	0.03
TBAD	***193.5***	***15.3***	***22.2***	***5.8***	***9.0***	***8.9***	***4309.3***	***10.9***	***62.4***	***6.1***	***34.6***	***8.0***
Confirmed Malaria	1001.4	7.9	95	23.86	23.3	23.02	3065	7.78	194.1	19.01	112.0	25.95
Suspected Malaria	1891	15	247.4	62.2	62.9	62.21	5441.2	13.81	536.4	52.53	280.9	65.04
URTI	46555	36.8	111.4	27.99	43.0	42.49	485.2	1.23	129.5	12.69	91.8	21.25
THV (New & Revisit)	12655	0.00	398.1	0	101.1	0	39400.3	0	1021.1	0.00	431.8	0.00

LRTI= Lower respiratory tract infection; ODRS= Other Diseases of Respiratory System; TBAD= Total for Biomass Associated Diseases;

URTI= Upper Respiratory Tract Infection; THV=Total Hospital Visitation

Source: KNBS (2021)

of respiration systems and pneumonia at the national level accounted for six percent each of the total hospital visitation in 2020. Among the children at the national level, the 15% hospital visitation associated with biomass cooking fuel were low compared to malaria instances (23%) and the upper respiration tract infections at 37%. It is however important to note that any disease is a cost to the community and hence reduction of their occurrence was preferred.

Despite the sub-counties in Vihiga and Bungoma reporting high usage of biomass cooking energy that was expected to account for a huge proportion of disease occurrence among community, incidences of malaria overshadowed other ailments in the two counties. The counties' disease occurrence that ranged between 6 to 8 percent was high for the farmers and their families. Illness to any of the household member affected the availability of labour, family members allocated more time to take care of the sick and it cost finances for treatment. Despite the relationship presented on biomass cooking fuels and community disease occurrence per annum, studies that clearly show causative are required. However, due to the association already presented in literature, reduction in indoor pollution resulting from biomass cooking fuel will reduce instances of the highlighted diseases (Prasad et al., 2012)

Production resources' trade-off between biomass cooking energy and food production

Evaluation of effect of biomass fuel use and demand on agricultural food production (Chapter 5) showed the two critical sectors to have both synergies and trade-offs. With a high proportion of household labour resource allocated to leisure, efforts in biomass energy fetching and agricultural production simultaneously spurred more labour to productive activities. Households who allocated more labour to biomass energy sourcing were also involved in much apportionment of the resource to agricultural production. As household labour became more abundance as presented by the proportion of adults in a family more was availed for productive activities. However, allocation of more labour resources to agriculture failed to assure increased maize yield.

Households' financial resources were observed to be competitive between biomass energy sourcing and agricultural production. Due to the stated competitiveness, a trade-off was observed between investments in agricultural and on biomass energy and vice-versa. It was however interesting to note that spending on non-agricultural and non-cooking energy (other) expenses reported synergies with either agricultural investment or cooking energy spending. Households spending more in other non-energy and non-agricultural expenses also spent more in either agriculture or energy. Households with high disposable income choose to either spent more in agriculture or in energy expenses A complex relationship were observed on capital investments where those households with more land ultimately apportioning more land to maize production and spent more in both agricultural financial investment and biomass energy spending.

Households allocating more land to maize production were able to achieve maize self sufficiency through own production. However allocation of more land to maize production had negative effects of the number of trees propagated and managed. The relationship between area allocated to maize and number of trees planted showed trade-off in land resource allocation. Synergies were observed between the management of many trees and high maize yield achievement. Characteristics of farmers who adopted tree farming had positive effects on maize yield achieved or trees had a helpful influence of maize productivity that could not be simply explained. The effects could have been associated with trees acting
as wind break or moderating maize growing micro-climate thereby reducing evaporation and improving pollination. It is also important to note that households managing large numbers of trees were more food sufficiency achievers through own production than otherwise.

From this review, instances of trade-offs and synergies were observed in terms of production resource allocations and systems operations. An abundance of resources, as in the case of labour yielded synergies between biomass energy and agricultural food production. Restricted availability of production resources resulted in competitive allocation and hence tradeoff between biomass energy and food production. Smallholders were more constrained in capital and land resources and hence had to choose which of the sector to invest in, either energy or food production. Also important were the synergies between energy and food production systems that were beyond bare production resource allocations.

7.1.3 Biomass cooking energy demands and tree farming

Critical to smallholders' adoption of tree planting was the desire for the households to meet their biomass energy demands. However, tree planting has led to many other benefits that have accrued not only to the smallholders but also the ecosystem. Trees were also sources of income and construction material (Tesfaye et al., 2020) and other utilities to households including provision of shade. Trees also boast agricultural production by providing livestock fodder, soil nutrients replenishment and condition improvement (Jose, 2009), wind-break and habitat for pollinators (Castle et al., 2022). Ecologically trees plays important role in greenhouse gas sequestration through photosynthesis process (Lin et al., 2022); micro-climate moderation and facilitates in water-cycle hence rainfall (Sheil, 2018). Most of the trees planted were exotic, and beyond the services already enumerated, farmed trees protects the indigenous forest from exploitation for biomass energy and even for timber (Castle et al., 2022; Tesfaye et al., 2020). The use of biomass energy and resultant drive in responding to the fuel energy shortage through tree planting was anticipated to have had positive impacts. However the key policy question is whether planted trees were able to sufficiently safeguard the natural forest and agro-ecology from destruction to meet households' needs and offer the ecosystem services to the agriculture sector.

Table 7.4 shows smallholders' adoption of tree management and own farm dependency on firewood collection among the sub-counties.

Table 7. 4: Households managing trees among smallholders of the sampled sub-counties area

	% dependency on own farm for firewood	% of those adopted tree planting	Average number of non-fruits trees managed	Average number of fruit trees managed	Total number of Trees per ha	Tree per capita
Overall	58	88	127	10	78	31
Bumula	74	92	204	11	99.2	43
Sabatia	59	89	72	13	102	21
North	69	87	151	10	54.	33
Elgon	35	86	97	7	63	28

Adoption of tree management was high, with on average 88% of all the households reporting to undertake this critical ecological function. Bumula had a slightly higher proportion of households adopting tree management due to the tree planting promotion associated with tobacco management agencies as they responded to energy requirement for the crop's curing. As a rule every area of tobacco planted by farmers required at least half of the same area of trees with the seedlings provided by the crop management agency (*BAT, Extension Manager, Malakisi Bungoma, personal communication*). It was for the same reason that households in Bumula had a higher average number and per capita tree statistics. The low acreage of land owned in Sabatia boosted the reported number of trees per unit area which was the highest among the sub-counties sampled. Despite the differences on the figures, all the measures on tree management were high including on the average numbers per household, per capita and unit area numbers. These high positive indicators of tree management among households contributed to the yet another encouraging output represented by the proportion of households that largely depended on their own farm for firewood gathering. Under this output Bumula, Bungoma North,Sabatia and Mt. Elgon recorded 74, 69, 59 and 35 percent respectively of households relying on own farm for firewood gathering. The high numbers on own farm dependency showed efforts by smallholders to achieve sufficiency by own production.

The low number of fruit trees managed by the households affirmed the main drive for tree management to be largely in response to energy sourcing. A comparison of the fruit tree to non-fruit trees managed ratio among the sub-counties showed Bumula, Bungoma North, Sabatia and Elgon to having 5, 8, 18 and 7 percent respectively. In this regards, Sabatia reported the highest proportion of fruit tree to non-fruit trees managed ratio. It has however to be noted that although the managed trees were largely non-food provider, their contribution to other ecological functions were high. Already, it has been observed that the number of trees managed was able to off-set the need of household gathering firewood from the forests or public land among most of them (i.e. 58% overall). The negative impacts of biomass resources harvested in respond to cooking energy demand as highlighted earlier are largely off-set by on-farm tree management. However it has to be noted that most of on-farm trees are the exotic with the farm stands mostly poor in diversity. The low diversity and exotic varieties of trees may not encourage fauna required for pollination especially the browsing insects particularly bees. Bees are not only necessary for pollination but are also critical agricultural enterprise yielding honey and other products for income.

Management of trees has been critical in Carbon sequestration an important process of reducing greenhouse gas from the environment (Lin et al., 2022). Reduction of greenhouse gas from the atmosphere remains the ultimate ecological intervention for addressing the climate change menace (Lwasa, 2017). Necessitating global agreements on greenhouse gas reduction including the Kyoto protocol (Kim et al., 2020) and the Paris Agreement (Pauw et al., 2019) which are key prevailing outcomes from the global community addressing climate change menace under the Intergovernmental Panel on Climate Change (IPCC). Moreover, most of the Carbon trading projects are based on tree planting and management where the polluter (greenhouse gas emitter) pays the trees owner due to the latter's roles in off-setting the former's emissions activities. It is also important to note that forest plantations in tropics are among the best in carbon sequestration globally (Lin et al., 2022; Yadav et al., 2022). With trees planting in an effort to respond to immediate households demand and exploiting further opportunities including carbon credits markets, countries get to develop local economy and also the macro-economic through exports (Shen et al., 2020). Progressively countries, companies and individuals are being invited to participate in greenhouse gas reductions as a responsibility towards global common good. Under Paris Agreement countries are required to report their National GHG Inventories from 2024 to help build trust and confidence that countries are taking action to meet their national climate (Pauw et al., 2019) mitigation impacts. With higher biomass cooking energy usage, developing counties will have to expand plantations to both meet immediate need and also protect existing forest as an indicator of their achievements. Necessity exists for the intervention on emissions offsets for the continued usage of biomass energy, notwithstanding the fact that the fuel might be sought specifically from plantation meant to meet the particular demand. It is important to affirm the role of trees in carbon sequestration especially among the smallholders and evaluate smallholding net effects on emission, thereby requiring estimation of planted trees roles in carbon sequestration.

7.1.4 The nexus between tree farming and greenhouse gas removal among smallholders

Estimation of the carbon removal by trees

Through the process of photosynthesis trees absorbs Carbon dioxide (CO_2) from the atmosphere and reduces it into carbohydrates and release Oxygen (O_2). Absorption of CO_2 from the atmosphere and its conversation to a climate change benign compounds make trees critical agents in mitigating the threat presented by climate change. This process which is concerned with the long-term storage of carbon in plants also accounts for what is referred to us carbon sequestration where the trees make carbon sink or reservoirs (Yirdaw, 2018). Trees planted by smallholders' role in carbon sequestration was estimated through methodologies described (Albrecht & Kandji, 2003; Henry et al., 2009; Woomer, 2003). Although the farmlands in western Kenya have various species of trees, Eucalyptus species accounts for the most of the trees propagated and managed (Henry et al., 2011). KEFRI (2012) has reported *Eucalyptus saligna*as the most common due to agro-ecological suitability and recommendations campaigns for its adoption by forest extension officers. Available

Table 7. 5: Tree biomass and Carbon Dioxide removal per individual for *E. saligna*

Age of a tree in (years)	Dhb (cm)	height	Dhb (cm)	Height (m)	AGM (kg)	Roots biomass (35% AGB)	Fineroots (15%AGB)	Leaves drop (15% AGB)	Total Biomass (kg)	AGM+ Root CO_2 ass
	Tree growth information						*biomass and Co2 removal per tree*			
2	9.6	10			20.9	7.35	3.2	3.15	35	63.5
3			12.7	13.5	39.8	14	6	6	66	121
4			16.3	19.5	80.9	28.35	12.2	12.15	134	245
5	20	23	18.5	22.5	141.0	49.35	21.2	21.15	233	426
6	22.5	25	20.3	25.5	192. 0	67.2	28.8	28.8	317	581
10	27.5	32			361.9	126.7	54.3	54.3	597	1095
15	33	34.5			556.0	194.6	83.4	83.4	917	1682
	(Walters, 1980)		(Whitesell *et al.,* 1992)							

NB: Assumption of 370-590 trees per acre., AGB = below ground biomass; BGB = below-ground biomass:

carbon removal estimation models include those on specific species (Henry *et al.,* 2011; Yirdaw, 2018) and generalized equations (Woomer, 2003).

The fitting of variables to existing allometric equations have been widely used (Henry *et al.,* 2009; Yirdaw, 2018) in estimating trees growth rate. Estimation of carbon removal has been facilitated by among others, listing of 850 allometric equations (Henry *et al.,* 2011) for various species in the sub-Saharan Africa. With agroforestry nature of the farming system, where trees are harvested for difference uses at varying ages, carbon removal could be estimated at large scale if assumed to be planted at a specific time and allowed to grow to particular age regimes. Table 7.5 shows the *E. saligna* growth model data that was triangulated with the survey information to estimate carbon sequestration information. Information derived from experimental results to aid in carbon removal estimation included on the trees' age, breast height diameter (dhb) gained, and height achieved, and respective carbon stock sequestrated in the above ground mass (AGM). More estimation of the role of trees in GHG removal included those of underground mass and organic matter. The specific studies used in developing age based CO_2 removal estimation were selected due to their conformity with the data requirement and the fact that they were done in similar locality (Beets et al., 2018). Models adopted for the estimation of AGM (Whitesell et al., 1992) are shown in Appendix *C4.*

The choice of growth model and calculation taken to estimate AGB was influenced by the wealth of data points and corresponding data point details on a particular year of tree growth. Carbon removal in roots biomass, fine roots, and the leaves dropped by a tree were extrapolated based on recommended simulations (Meng *et a*l., 2018; Woomer, 2003).

Table 7.6 shows Carbon dioxide sequestrated by managed trees in the sub-counties based on the model adopted and an assumption of all trees being planted at the same time and with specified growth periods. In a five, 10, and 15 years period, the available trees would have accumulated on average Carbon equivalent to the absorption of 47, 120, and 184 tonnes of CO_2e for each of the sampled households. Optimal age for Eucalyptus tree harvesting was between 8 to 10 years *(Gordon Omollo, Forester Comply Company, Personal Communication)* when they were ready and made the highest commercial return to farmers. Farmers reported *(through focus groups discussion)* harvesting of the trees to be mostly influenced by financial emergencies that routine income could not cover including school fees, medical or construction requirement with trees harvested any time after seven years. In this regards trees stands as old as above 20 years were being managed as they acted as emergency collateral. It was also reported that instant market for trees existed for timber and fuels in schools and households. If the trees were allowed to grow for 10 or 15 years duration, an annual carbon stock equivalent to 12 and 12.3 tonnes respectively would have been accumulated annually.

Households in all the sub-counties except Mt. Elgon were able to offset the 2017 emissions associated with biomass cooking energy through tree management. In Mt. Elgon, biomass energy associated emissions in 2017 were higher that they could not be offset by tree numbers being managed annual CO_2e accumulation at neither 10 nor 15 years of harvest. The number of trees managed by the smallholders in Bumula and Bungoma North were able to offset the 2017 total emissions even at annual CO_2e accumulation if trees were harvested at 10 years. Despite the levels of total household emissions reported in Sabatia being the lowest in 2017 compared to other sub-counties, the number of trees managed was low that it could not offset even the little emissions reported.

Trees' management beyond providing biomass fuels which accounted mostly for the twigs used (FGD outcome) and contributed largely to own farm dependency on biomass were critical in offsetting emissions thereby ensuring ecological stability and improvement (Moore et al., 2023).

Conclusions

A review of the nexus between cooking energy, food production, and greenhouse gas emission in smallholder farming showed a lot of interlinkages between the components. Staple food production and biomass energy sourcing (gathering and production) take place simultaneously in the smallholding farming system. Synergies were observed between production systems of maize and trees, resulting in the reported maize yield increase. Both cooking energy gathering and food production activities led to increased labour allocation to productive uses from leisure. Trade-offs was observed in capital and land allocation between biomass energy production and food production. Presence of synergy or trade-off between cooking energy and food production appeared to be influenced by availability of the productive resources. Farmed trees played a critical role in availing biomass energy sources, improving agro-ecology for food production, being a source of income and off-setting the GHG emissions for households operations and hence mitigating climate change.

Table 7. 6: The role of tree farming on greenhouse removal in western Kenya

Trees and maize variable	Elgon	North	Bumula	Sabatia
Total number of trees per household	104	161	214	85
5 years CO_2e accumulation (ton) for *E.saligna*	44	69	92	36
10 years CO_2e accumulation (ton) for *E.saligna*	114	176	235	93
15 years CO_2e accumulation (ton) for *E.Saligna*	175	270	361	143
Annual CO_2e accumulation if tree harvested at 10 years	11.4	17.6	23.5	9.3
Annual CO_2e accumulation if tree harvested at 15 years	11.7	18.1	24.1	9.5
2017 Emissions associated with biomass cooking energy CO_2e intonne	12.031	8.627	8.89	6.65
2017 Emissions Total household emissions CO_2e in tonne	16.27	13.63	13.35	10.05
Net CO_2 offsets for 10 years accumulation	-0.63	8.97	14.61	2.65
Net CO_2 offsets for 15 years accumulation	-4.9	4.0	10.15	-0.75

7.2 Conclusions

Several conclusions were derived from this study in relation to the specific objectives of the research.

7.2.1 Characterisations of the socio-economic, food production and cooking energy among smallholders in sub-counties of western Kenya.

i. Despite western Kenya having been studied as a homogenous region, some heterogeneity was observed on agro-ecological zones, soil types, climatic factors, altitude, population's density, cropping patterns and cooking energy sourcing. An analysis of socio-economic characteristics showed some differences among the sampled cluster sub-counties. However, the few differences revealed were not across all the sub-counties but between a sub-county in relation to another or others. The differences observed on socio-economic factors included the household members' composition and structure in age and gender, formal employment status, title deeds ownership, credit access, dependency of own farm for biomass energy, sufficiency in maize staple food through own production, biomass energy-saving efforts and consciousness of warming environment as household choose on cooking energy.

ii. Allocation of labour to productive and reproductive responsibilities women head of the family (mother) assigned more hours in relation to other members of a household as categorised by the gender and family structure. A 'mother' accounted for 41% and 68% of total household's labour time for agricultural production and cooking energy sourcing respectively, with other members including the father, other relatives and hired employees accounting for the rest of the time proportion.

iii. Severe and endemic food insecurity prevails in western Kenya calling for technological, policy and information dissemination interventions that will mitigate the observed food challenges

iv. Household food availability status among smallholders was observed to be associated with the duration of the year as influenced by agricultural production seasons. Food availability sufficiency status was reported to be highest (16% to 18% of households) between September to December when maize was being harvested and processed. In the same duration, food insufficiency status was the lowest as reported by 11% to 14% of households, dependency on own food production was highest (about 85%) and more quantity of maize was used on average at 52kg per household.

v. Higher levels of food insufficiency reported by 36% to 50% of households occurred between April and July. This duration of higher food insufficiency was also associated with food sufficiency reported by as low as 7% of households, average monthly household consumption of 46kg of maize and less than 60% dependency on own food production. In the same season, household were relying more on market for maize than at any other time and were resulting in other non-staple foodstuffs. This season of challenges in food access was the furthest in time from harvest and just before the next maize crop could be ready for harvest.

vi. Ease in access to cooking energy was also associated with annual agricultural production seasons as influenced by rainfall patterns. In the months between September and December; and January to February, the lowest proportion of households (less than 15% and 10% respectively) reported cooking energy insufficiency. In these seasons of relative ease in energy access, households reporting sufficiency in cooking energy availability was the highest at between seven and nine percent. The duration coincided with when households increased utilisation of agricultural crop waste from about one to twenty percent and had reduced dependency on firewood to as low as 60%.

vii. The months of April through July were associated with a higher proportion of households (20% to 25%) reporting insufficiency in cooking energy status. The season also coincided with when the lowest proportion of households (less than 4) reported sufficiency in cooking energy; households' utilisation of twigs increased slightly to above 10% of cases, and the of use agricultural crop waste was insignificant.

viii. Similarities were observed between staple food availability and cooking energy sources sufficiency trends in a year. The season when sufficiency in food availability was higher among households coincided with the duration when a larger proportion reported sufficiency in cooking energy, and vice versa.

ix. The observed cooking energy sourcing situation where only less than nine percent of households reported sufficiency at any time of the year could be considered as energy poverty.

x. Overall the levels of households' food sufficiency through own production differed among the smallholders. Only about a third of the households were able to meet their food demand from their own productions in 2017. This observation affirmed the high prevalence of food insecurity as an indication of food poverty among maize producers.

The food sufficiency status in Vihiga County was more distressed than in all the other sub-counties sampled.

7.2.2 Factors influencing cooking energy sources among households in western Kenya

i. Provision of cooking energy sources was a key activity among households that were allocated resources similar to those required for agricultural production including the capital, labour and land for biomass production.

ii. Firewood was the most popular cooking energy source preferred by the households using it for breakfast, lunch and supper respectively. Other biomass types of cooking energy also account for a substantial proportion of cooking energy including twigs, charcoal, sawdust and agricultural crop wastes,

iii. Preference for LPG as a cooking energy choice was lower and mostly associated with breakfast preparation and household informal employment. Significant factors that positively influenced preference of LPG in relation to firewood included per capita consumption expenditure and formal employment for the household head. It, therefore, implied that any intervention that will enhance preference of LPG and influence conservation of biomass will entail increasing returns from agriculture.

iv. Factors with less likelihood for influencing preference of LPG in relation to firewood as cooking energy choice included households with a larger proportion of members being adults and those enjoying credit facilities.

v. Households pursued cooking energy sources sufficiency by planting trees. The exploitation of own trees for firewood by households was mostly through trees' pruning that yielded twigs. Households facing higher costs of firewood, and those with few houses were more likely to prefer twigs than firewood as a cooking energy choice. Twigs were observed to be inferior cooking energy.

vi. Despite sub-counties differences in agro-ecological zones and perceived biomass energy demand as influenced by local industry using biomass energy and vicinity to natural forests, the farming community in the sampled area could be considered as homogenous on cooking energy sourcing and determinants of preference on optional fuel used.

vii. The probability of households in western Kenya preferring firewood as a cooking energy source choice was 90%, 92% and 97% for breakfast, lunch and supper preparations respectively.

viii. Households concerned with the warming house environment when choosing cooking energy; those with longer distances covered to fetch firewood and those with a higher per capita expenditure had increased likelihood for preference of agricultural crop wastes rather than firewood for breakfast preparation.

ix. The use of agricultural waste, mostly maize cobs were associated with cooking during cold seasons or supper when the households were also yearning to warm the residence environment.

x. Study outcomes were consistent with other concepts associated with cooking energy usage, including the transition energy ladder and energy stacking.

7.2.3 Trade-off of households' biomass energy utilisation and farming on food production among households in western Kenya;

i. Labour availability among the sampled sub-counties could be considered to be abundant with only 34% of the total allocated to productive activities. Adult time allocated to productive activities including agriculture (67%), biomass energy sourcing (5%) and off-farm employment (28%).

ii. Economic model analysis outcomes showed maize yields to be significantly influenced by age of household head, the number of trees managed, agricultural labour allocated and amount of basal (DAP) fertiliser applied on maize.

iii. Labour allocation to agricultural production was significantly and directly influenced by the amount of labour allocated to biomass gathering. The observed relationship was an indication of synergies between agricultural production and the use of biomass cooking energy sourcing. Other factors that influenced labour allocation to agriculture included the number of individuals in a household and the proportion of adults.

iv. Capital allocation to agriculture by households was significantly influenced by spending on other non-agriculture and non-energy activity costs, and the area allocated to maize. This observation implied that those farmers who had more disposable income were able to spend more on agricultural production as well as other households' needs.

v. Determinants of land resource allocation to agriculture included the number of tropical livestock units reared and other sub-counties (locational) characteristics. For example, the allocation of land to agriculture in Sabatia was less than those in Bungoma North due to resource availability as influenced by population densities in each of the sub-county.

vi. Synergies were observed between the number of trees managed and the yield of maize achieved, and the labour allocated to agriculture and that allocated to biomass fuels gathering.

vii. High spending on cooking energy had negative effects on the amount invested in agriculture. Although the allocation of more land to maize increased the achievement of food sufficiency in the household, it led to decreased number of trees managed.

7.2.4 Levels of agricultural households' greenhouse gas emissions and factors influencing the levels of emissions in western Kenya

i. Incorporation of both the 'bottom-up' and 'top-down' greenhouse gas evaluation approaches enabled the assessment of maize farming smallholders' system's GHG emissions.

ii. Emissions associated with maize farming smallholding systems were attributable to maize production (47%), cooking energy usage (37%), livestock management (13%) and lighting energy (3%).

iii. Key emission activities associated with maize production included those related to applications of synthetic fertiliser (Diammonium Phosphate_DAP for basal applications and Calcium Ammonium Nitrate_CAN for top-dressing), organic manure; maize farming soil manipulation; and maize waste disintegration.

iv. The use of maize stalk and cobs as cooking energy sources, despite also being linked to emissions was important in mitigating higher levels of emissions associated with maize waste disintegration.

v. On average every individual in the sampled area emitted 6.57 tonnes of CO_2e in 2017.

vi. Emission associated with livestock management was estimated at 2922Kg CO_2e with cattle, goat and chicken accounting for 2766, 158 and 0.021 respectively.

vii. Production of a kilogramme of maize was associated with 5.84 kg CO_2eq. with DAP, CAN and manure utilisation accounting for 0.041kg, 0.06kg and 0.24kg CO_2e respectively. Decomposition and natural soil process contributed 4.72kg and 0.75kg CO_2e respectively of emission associated with a unit production of maize.

viii. The Household's average annual GHG emissions associated with cooking energy and lighting energy was 9657Kg CO_2e.

ix. Significant factors that influenced households' GHG emission levels included the household size, amount of land owned, number of tropical livestock units reared, maize yield achieved and location factors as influenced by area allocated to maize and dependency on the public forest for firewood.

x. The amount of emission reported per individual could be significant in influencing climate change if all the persons involved in smallholding were to be considered. The effect of climate change on the globe has been postulated to impact agriculture with the smallholding system being more vulnerable.

7.2.5 General discussion and conclusion

i. Smallholding in western Kenya was observed to be a complex farming complex involved in food and biomass cooking energy production, offering other ecology functions of trees and climate change mitigations.

7.3. Recommendations

A number of recommendations are presented based on the outcome of the study in relation to specific objectives

7.3.1 Characterisations of the socio-economic, food production and cooking energy among smallholders in sub-counties of western Kenya.

i. Governments both counties and national, and other development agencies should pursue policy interventions that will improve the reserve price of productive activity including agriculture and off-farm employment to encourage households' labour allocation to these economic sectors. Strategy to increase reserve prices for agriculture includes improved agricultural productivity and profitability. The improved agriculture profitability would boast local rural off-farm employment consequently attracting labour allocation to these two sectors. Increased agricultural productivity will also boost food security in all months of the year.

ii. Farmers should adopt the high yielding agricultural technologies to boost their staple food production and consequently increase food self-sufficiency in all months of the year and income from surplus sales. Moreover, the same interventions should mitigate challenges on biomass cooking energy access at anytime and in all months of the year.

iii. Governments and other development agencies should develop and promote technologies associated with the storage of both food and agricultural waste as energy sources. Other technologies that may mitigate challenges associated with biomass cooking energy will include cooking energy-saving technologies.

iv. Governments and other development agencies should promote gender equity in labour allocations to avoid situations where some households allocate more duration of productive labour to some members (mother), while others have most of their time in leisure.
v. More research should be undertaken in relation to improving households' agricultural production, food availability across all the months of a year, increased agricultural income that boosts off-farm employment; enhancing households cooking energy security; and increasing household labour allocation equity among members.

7.3.2 Factors influencing the choice of cooking energy sources among households in western Kenya.

i. Despite its wide adoption as a cooking energy source, biomass is a dirty fuel that is not only associated with negative health concerns but also competes for resources with agricultural production. Efforts should be put in place to initiate households’ transition from biomass energy sources to LPG and with the transition expected not to be immediate mitigations on biomass energy continuous will include households planting of trees.
ii. Efforts to increase the preference for cleaner energy sources mostly the LPG should target improving farmers' financial welfare and social pride to match those associated with formally employed. Breakfast should be targeted as the meal type that would deliver effective cooking energy transition to LPG outcomes.
iii. Any sound and effective intervention designed for increasing the adoption of a cleaner energy sources in a sub-county could yield consistent outcomes across western Kenya due to observed homogeneity in cooking energy consumption behaviours.
iv. Increased yields of maize not only improves the food security and households’ incomes arising from surplus maize sales but also ensures a source of cooking energy option

7.3.3 Trade-off of households’ biomass energy utilisation and farming on food production among households in western Kenya

i. Governments and other development agencies should utilise the observed positive synergies between agricultural production and cooking energy source to initiate rural development incentives that would drive peasants’ transformation. Improves households' food security and transitions to cleaner cooking energies particular the adoption of LPG are the desired outcomes of the rural transformation.

7.3.4 Levels of agricultural households' greenhouse gas emissions and factors influencing the levels of emissions in western Kenya

i. The methodology used for the assessment of greenhouse gas emissions among maize farming systems in western Kenya could be extended to include other crops' enterprises cultivated by smallholders across the globe. This methodology could be replicated for the use of the National GHG's Inventory Reporting for countries where agriculture is largely by smallholders including Kenya.

ii. High dependency on biomass cooking energy does increase GHG emissions in the atmosphere thereby contributing to climate change. Moreover cutting of trees for biomass cooking energy deprives the vegetation biomes of their ecological functions of absorbing GHG gas and hence climate change regulations.

iii. Increasing efficiency in resource utilisation that boosts agricultural productivity including yields will be critical in mitigating climate change effects. Since agricultural production has to be continued to meet the increasing food and fibre demand, higher yields will ensure per unit fixed resources' emissions are at their lowest.

7.3.5 General discussion and conclusion

i. Since smallholding is a complex production system involved in not only addressing households' welfare through provision of food, cooking energy, income, and reaction, but also responding to ecological welfare through reforestation it would be important to use the nexus approach in tachling its development or intervention. .

7.4 References

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APPENDICES

Appendix A: Research tools used

Appendix A1, Energy-Agriculture synergy survey for smallholder

1. Date ____________________ Village ______________ Ward _________Sub-County _________
2. House head Name (optional) ____________________ _______ Household head Sex _____
3. Respondent's relationship to household head ______________ Respondent mobile no. _______
4. Age of household head____________________ Respondents experience in farming ______ yrs.
5. Is the household head in formal employment _________ if yes which sector ________________
6. Household size and education information

Household member (*those depending entirely on HHH for food & have no other home)*	Sex of member	Approx. age	Last completed class/ level in school	Where member is mostly engaged	If working full time in farm about what proportion of time spent engaged in farm	Time spent gathering firewood per outing	How regular is member involved in fire wood collection (daily, weekly etc)	Distance to where firewood is collected	Ownership of land where firewood is gathered	Daily requirement sufficient of firewood gathered/ member	Time spent on off-farm employment
Father											
Mother											
1st Child ( )											
2nd Child ( )											
3rd Child ( )											
4th Child ( )											
5th Child ( )											

6th Child ( )											
7th Child ( )											
8th Child ( )											
Other relatives (specify) 1.											
2.											
3.											
Employee 1											
Employee 2											
Employee 3											

7. Could you estimate how much money you spent on food (include even those you got from own farm) in the last one week ____________________________________
8. What proportion of food produced is consumed at household ___________________ what could be its estimated value ______________________________
9. Approximately how much did you spend on education last year? __________________________
10. Approximately how much did you invest in agriculture last year? ____________________________
11. Which is the other major expense for the household ________________ how much used Last yr _
12. What is the total land owned by household in acres? ____________ Is there any rented land and how much _____________________ in acres. Does the family lease out land and how much ____
13. Land allocated to various crops and its proportions for agricultural production 2017

Crop/enterprise	Acreage under crop Season 1	Approximate proportion of land	Crop yield achieved (kg)	Fertiliser application B & Td	Acreage under crop Season 2	Approximate proportion of land	Crop yield achieved (kg)	Fertiliser application B & Td	How much more of land do you need for suffiency of targeted amount	Is labour /capital a challenge in each of these land management (L=Y, C=Y

Homestead compound										
Fallow land (seasonal farmed)										
Pasture for livestock										
No of trees owned (non-fruits)										
Hedges trees										
Forest stands										
Area affected by trees reducing agricultural production										
(other crops propagated should be listed below with other related information)										

14. Have the title deed to this land been issued by government ______, If yes, is it in your name _ Whose name is in ______________________ What is the use rights for the land ______________
15. How much is it to hire an acre of land for farming _____. How much is it to buy an acre of land here __
16. Is the household involved in other off-farm businesses ________ If yes, which one ____________
17. What contribution of your income is accounted by i) agriculture ________ % ii) business ______% iii) employment _____________%.
18. Have you been receiving any credit? YES [ ] NO [ ]. If yes from where _________________________

19. Are you a member of any farmer group? YES [ ] NO [ ]

Energy utilisation in households

20. Household with a solar panel for house lighting [YES]   [NO]

21. Do you think energy for cooking is a challenge for your household? [YES]   [NO].   If yes, is it a challenge in sourcing the cooking fuel (YES) (NO) OR in the cost of purchasing [YES]   [NO].

22. Which strategies have you adopted in response to changes in ease of accessing your tradition cooking energy? (List and rank these intervention on your prioritisation)

Coping strategy	**Ranking the strategy (Prioliitized awarded 1)**
a. ______________________________	____________________
b. ______________________________	____________________
c. ______________________________	____________________
d. ______________________________	____________________
e. ______________________________	____________________
f. ______________________________	____________________

23. Mostly, how many meals are made by the household per day? _______________. In which proportion are the following meals made in the household per week **1.** Breakfast __________ 2. Lunch _____ 3. Supper ________.

24. Household choice of cooking energy

		Power	LPG (Gas)	Charcoal	kerosene	Firewood	Twigs	Agricultural crop wastes (maize stalks	Cow dung	Saw- dust
Break-fast	No. of people meal is made for _______				Meal					
	Duration of cooking _____									

	What is mostly cooked _____									
Ranking of use (9 mostly used, 0 not used										
Lunch	No. of people meal is made for_______									
	Duration of cooking _____									
	What is mostly cooked _____									
Ranking of use (9 mostly used, 0 not used										
Supper	No. of people meal is made for______									
	Duration of cooking _____									
	What is mostly cooked _____									
Ranking of use (9 mostly used, 0 not used										

25. How many houses are used by household members _____________ Do you intentionally and solely warm the houses [YES] [NO]

26. Do you have a separate kitchen from the main family's house [YES]   [NO]

27. Quantity and cost of energy sources utilised

Fuel type	Approximate total cost (weekly)	Ranking as most depended/used cooking energy (Highest=1)	Ranking as most depended lighting energy (Highest=1)	Ranking as most preferred cooking source if cost & access not limiting	
Firewood					
Charcoal					
Kerosene					
Crop's waste					
Cow dung					
LPG					
Electricity					

28. Have you adopted an improved stove for cooking [YES] [NO]

29. Food availability and access status for the household

Months	Staple food	Food Security status/ challenge in the family	Foregone meal proportion	Household sources proportion	Purchase proportion	Food challenge majorly contribute by		
						low production	Income	price
January								
February								
March								
April								
May								
June								
July								
August								
September								
October								
November								
December								
	Food availability challenges:- Extremely Severe, Severe, Concerning, Sufficiency, Highly Sufficiency,							

30. Does the household have cattle ________ If yes, how many are owned ________

31. Which uses is put to the cattle dung?

i) ……………………………………………

ii) ……………………………………………

32. Number of goats/sheep owned by household ……… Number of chicken owned by the household ……..…

WEIGHT MEASURE BY RESEARCHER

33. Weight of firewood collected (buddle) per day by family members . …………………

34. Weight of firewood (buddle) used for cooking per day by the household . …………………

35. Weight of maize stocks collected (buddle) per day by family members . …………………

36. Weight of other crop wastes used for cooking by household . …………………

37. Weight of maize stock used for cooking per day by household. ……………………………

38. Proportion of days household uses maize stock and other crop waste for cooking per year /month ……………………………….

39. Weight of cow dung collected per day by family members . …………………

40. Weight of cow dung used for cooking by household per day . …………………

41. Weight of charcoal used per day by household for cooking . …………………

Appendix A2: Checklist of questions for the focus group discussion

1. Ensure you have the names of all participants
2. Ensure you have gender of all participants
3. Establish the durations members have been settled and involved in agriculture in the area
4. Establish the historical aspects of agriculture in terms of crops husbandry and livestock management
5. Establish participants opinions on if agricultural production, productivity and returns have been improving or worsening
6. Get a highlight of critical drivers that changed the course of settlement, farming systems, agricultural production, maize yields and its contribution to farmers' welfare.
7. Establish participants opinions on the access to energy sources and if the situations has been improving or worsening
8. Establish the historical aspects of energy sourcing and use.
9. Establish the historical aspects of tree planting and its drivers.
10. Establish key annual activities of maize production and other agricultural activities
11. Establish key annual activities associated with energy sourcing and use
12. Establish existence of relationship between maize/agricultural production and cooking energy/ biomass energy sources
13. Establish other domestic activities that have implications on agricultural production and energy sourcing
14. Establish the relationship between the other domestic activities on one side and agricultural production and energy sourcing separately, and simultaneously.
15. In general is the cost of renting/leasing an acre of land in your neighbourhood?
16. What are the charges for hiring a labourer to work in a farm in your neighbourhood (Establish the duration of work in hours and if charges differs by year's seasons and by type of farming chores.
17. Participant should be allowed to raise any other information concerned with agricultural production and cooking energy sourcing.

Appendix A3 List of key stakeholders consulted

i	Forest Manager, Mt Elgon
ii	Assistant Forest Manager, Mt. Elgon
iii	Sub-County Forest Officer
iv	Sub-County Agricultural Officer, Sabatia
v	Vice-Chairman, Community Forestry Association, Kamuneru
vi	Chief, Kamuneru
vii	Mundete Tea Factory, Field Services Coordinator
viii	Chief , Bumula
ix	BAT, Field Extension Manager
x	Deputy County Commissioner, Sabatia
xi	Deputy County Commissioner, Mt. Elgon
xii	Chief, Naitiri
xiii	Comply Company, Forest Officer
Xiv	VI Agroforestry Officer, Naititi Offices , Bungoma North

List of key focuss groups discussion sessions

i	2 Focus Group Discussion sessions in Mt Elgon
ii	2 Focus Group Discussion in North Bungoma, (Naitiri)
iii	2 Focus Groups Discussion in Bumula
iv	1 Focus Group Discusiion in Sabatia

Appendix B. Research approval letters

Appendix B1. NACOSTIC approval letter

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY&INNOVATION

Ref No:**157261**

20/January/2020

Date of Issue:

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SMALLHOLDER FARMERS IN KENYA: A CASE STUDY OF WESTERN KENYA for the period ending : 20/January/2021.

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Appendix C: Reference indeces used

Appendix C1: Adult equivalent conversion factors for varies ages and gender

Age/Gender categories	Calories (kcal.) requirement per day	Adult equivalent conversion factor
New		
0-1	750	0.29
Children		
1-3	1,300	0.51
4-6	1,800	0.71
7-10	2,000	0.78
Men		
11-14	2,500	0.98
15-18	3,000	1.18
19-24	2,900	1.14
25-50	2,900	1.14
51+	2,300	0.90
Women		
11-14	2,200	0.86
15-18	2,200	0.86
19-24	2,200	0.86
25-50	2,200	0.86
51+	1,900	0.75
Breastfeed	Add 500	Add 0.20
Pregnant	Add 300	Add 0.12
Source: Claro et al. 2010		

Appendix C2:Post regression Variacle Inflatory Factors for variable used in MNL analysis to test for multicollinearity

Variable	VIF	1/VIF
Household enjoying credit facilities	2.69	0.371079
Membership to farmers group	2.63	0.379641
Sqrt_2017 agricultural investment (KES)	2.44	0.410033
household size (no.)	2.05	0.488752
Sqrt_ Distance to firewood gathering	1.98	0.505983
Sqrt_2017 Maize production (kg)	1.7	0.587365
Household head years of formal education	1.68	0.593885
Proportion of adults (%) propadults	1.63	0.612148
sqrtfwdis	1.61	0.621207
Own farm firewood reliance	1.47	0.680333
Household head formal employment	1.42	0.706311
Sqrt_Weekly firewood cost (KES)	1.38	0.725238
Sqrt_duration per outing of firewood (min)	1.37	0.729441
Adoption of improved cooking stove	1.35	0.739482
Members gathering firewood (no)	1.35	0.740541

Household head gender	1.32	0.75916
Number of houses in a household	1.31	0.762109
Sqrt_ Distance to firewood gathering	1.31	0.762996
Adoption of solar energy	1.28	0.782314
Sqrt_proportion of female	1.24	0.809478
Own food production proportion (%)	1.22	0.822578
Log_ daily per capita expenditure (KES)	1.19	0.842245
Conscious of warming the house	1.15	0.867325
Mean VIF	1.6	

Appendix C3: Tropical livestock unit (TLU) conversion factors for varies animals

Livestock	Tro[ical livestock Unit index
Cattle	0.7
Sheep	0.1
Goat	0.1
Chicken	0.01
Piga	0.01
Source: Ostrow et al. 2020	

Appendix C4

Equations adopted for Above Ground biomass (AGB) estimation (Whitesell *et al.* 1992) in estimating Carbon sequestration oin trees

$Y_t = 0.12022\ xD^{2.1448}x\ H^{0.13\ 5\ 2}$ 1 (Adopted for trees below 4 years)

$Y_t = 0.01996\ xD^{1.9144}x\ H^{0.9976}$ 2 (Adopted for trees 4 years and above)

Appendix D. Analysis outputs

Appendix D1. Outcome of CHI square Beneforri analysis

TABLE C-1: OUTCOME OF CHI SQUARE BENEFORRI ANALYSIS

Solar Pr = 0.000	Bumula	Mt.Elgon	North	Sabatia
Bumula		χ^2=0.7899 p= 0.374	χ^2=2.0203 p= 0.155	χ^2=13.4030 p= 0.000
Mt Elgon			χ^2=6.0624 p= 0.014	χ^2=8.8295 p= 0.003
North				χ^2=28.6379 p= 0.000

Formal employment	Bumula	Mt.Elgon	North	Sabatia
Bumula		χ^2=1.1202 p= 0.290	χ^2=2.2236 p= 0.136	χ^2=0.1219 p= 0.727
Mt Elgon			χ^2=7.1900 p= 0.007	χ^2=0.5576 p= 0.455
North				χ^2=3.8789 p= 0.049

Hhs	Bumula	Mt.Elgon	North	Sabatia
Bumula			χ^2=0.0869 p= 0.768	χ^2=0.9397 p= 0.332
Mt Elgon	χ^2=2.7682 p= 0.096		χ^2=4.5202 p= 0.033	χ^2=0.5763 p= 0.448
North				χ^2=1.8682 p= 0.172

Fw_farm 33.0829 Pr = 0.000	Bumula	Mt.Elgon	North	Sabatia
Bumula		χ^2=24.1662 p= 0.000	0χ^2=.2780 p= 0.598	χ^2=4.2492 p= 0.039
Mt Elgon			χ^2=23.2839 p= 0.000	χ^2=10.0316 p= 0.002
North				χ^2=2.8648 p= 0.091

Credit	Bumula	Mt.Elgon	North	Sabatia
Bumula		χ^2=8.3079 p= 0.004	χ^2=1.4190 p= 0.234	χ^2=3.9110 p= 0.048
Mt Elgon			χ^2=3.3027 p= 0.069	χ^2=0.9288 p= 0.335
North				χ^2=0.7293 p= 0.393

farmergrp	Bumula	Mt.Elgon	North	Sabatia
Bumula		χ^2=5.5065 p= 0.019	χ^2= 0.5077 p= 0.476	χ^2=1.3288 p= 0.249

Mt Elgon			χ^2=3.0503 p= 0.081	χ^2=1.5952 p= 0.207
North				χ^2=0.2286 p= 0.633

tdgovt	Bumula	Mt.Elgon	North	Sabatia
Bumula		χ^2=17.9313 p= 0.000	χ^2=0.0089 p= 0.925	χ^2=0.1531 p= 0.696
Mt Elgon			χ^2=19.7565 p= 0.000	χ^2=23.9304 p= 0.000
North				χ^2=0.2711 p= 0.603

Improvjiko	Bumula	Mt.Elgon	North	Sabatia
Bumula		χ^2=17.9019 p= 0.000	χ^2=0.0581 p= 0.809	χ^2=2.5991 p= 0.107
Mt Elgon			χ^2=22.4691 p= 0.000	χ^2=7.8560 p= 0.005
North				χ^2=3.9475 p= =0.047

swh_warmhouse	Bumula	Mt.Elgon	North	Sabatia
Bumula		χ^2=2.4605p= 0.117	χ^2=0.2847 p= 0.594	χ^2=6.0184 p= 0.014
Mt Elgon			χ^2=5.1099 p= 0.024	χ^2=0.9805 p= 0.322
North				χ^2=10.3518 p= 0.001

Appendix E. Abstract for published papers

Appendix E1:ABSTRACT FOR JOURNAL SUBMITTED PAPERS (Submitted to Agricultural System)

Do smallholders have a role to play in atmospheric greenhouse gas levels? Insights from western Kenya

Francis M. Mwaura[1]*, Margaret W. Ngigi[2] and Gideon Obare[2]

[1]Dept. of Agricultural Economics & Rural Development, University of Eldoret, [2]Dept. of Agricultural Economics & Agribusiness Management, Egerton University.

Abstract:

CONTEXT: The threat presented by climate change has forced the international community, countries and other institutions to set targets for reducing emissions or enhancing removal of greenhouse gas estimated as carbon dioxide equivalent (CO_2e). That notwithstanding, comprehensive strategies for enumerating some stakeholders' roles, including smallholders are yet to be designed and tested.

*OBJECTIVE:*The study sought to 1). determine the smallholders' net role in GHGs' removals; 2). assess the presence of differences in smallholders' emission status for an identical system but in dissimilar agro-ecological zones as presented by sub-counties; 3). relate atmospheric GHG removers to households' socio-economic characteristics and 4). enumerate a cost effective approach of estimating atmospheric greenhouses gas emissions and removal by the smallholders.

METHODS: Survey of smallholders involved in maize based farming system in western Kenya was undertaken in 2018. A multi-stage sampling procedure involving purposive, stratified and random was used to sample 388 respondents in four sub-counties representing heterogeneity in agro-ecological zones and postulated biomass cooking energy access and demand. A questionnaire was used to query information on households' socio-economic, farming and cooking energy characteristics.Greenhouse gas emissions and removal activity data, default emission factors and outcomes of allometric equations based from existing secondary sources were incorporated into database from the survey to derive smallholders' roles as net GHG removers. Economic models were used to derived the drivers of GHG removers among smallholders.

RESULTS AND CONCLUSIONS:Most smallholders were net CO_2e removers with differences among them and the sampled sub-counties associated with intensity in adoption of the maize-agroforestry system and levels of biomass utilisation. Net CO_2e removers significantly *($p<0.05$)* reared more livestock, utilised more fertiliser at both planting and topdressing stages, reported higher maize yields and had planted more trees than those who were net dischargers. Factors influencing the probability *($p<0.05$)*of smallholder being a net carbon remover included household size, maize yield, land owned and adoption of energy saving cooking stoves. Emission mitigation practices were compatible with food security, agricultural commercialization and the welfare enhancing production operations.

*SIGNIFICANCE:*The study findings present an inexpensive and practical strategy of enumerating smallholders' role in CO_2e sequestration that could highly enhance developing countries reporting the National GHG Inventories and pin-point intervention options.

Keywords: peasants; carbon-sequestrations, climate change, emission mitigation, sub-Saharan Africa

Appendix E2: ABSTRACTS FOR PUBLISHED JOURNAL ARTICLES

i). Journal of Energy in Southern Africa 32(2):41-58 DOI:10.17159/2413-3051/2021/v32i2a8917

Journal of Energy in Southern Africa

Volume 32 Number 2
May 2021

Drivers of cooking energy choices by meal-types among smallholder farmers in western Kenya

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Abstract

There are gaps in research needed to enhance policy intervention for rural households' transitions from traditional biomass to cleaner energy sources. This paper reports on a survey among farmers in western Kenya to assess drivers of cooking energy choices for various key meals; to understand agricultural production factors in cooking energy choices; and to assess energy use homogeneity among varied sub-counties. The study sampled 388 respondents from four heterogeneous rural sub-counties differing in altitude, proximity to public forests, and cultural characteristics. The multinomial logit model analysis showed that significant factors influencing the shift from firewood to LPG for breakfast preparation included access to credit, income, formal employment, and the proportion of adults in the household. Shifting from firewood to crop wastes was significant, influenced by distance covered to collect firewood, and desire for warming houses. The shift from firewood to sticks was influenced by firewood cost, houses owned, and reliance on own farm for woodfuel. Determinants of cooking energy choices for breakfast, lunch and supper were identical. Sticks were seen as an inferior cooking energy source. The adoption of cleaner energy was more associated with breakfast than other meals. Despite the sub-counties' heterogeneity, no substantial differences were observed among them on drivers of cooking energy choices. Study outcomes were consistent with other concepts associated with cooking energy usage, including the transition energy ladder and energy stacking.

Keywords: *biomass; subsistence; environment; transition; poverty, Southern Africa*

ii). *African Journal of Education,Science and Technology*, *7*(1), Pg 277-293.
https://doi.org/https://doi.org/10.2022/ajest.v7i1.785

Agricultural Productivity and Labour Allocation Trade-Off Crises for Agriculture, Cooking Energy Sourcing and Off-Farm Employment in Developing Countries: Evidence from Western Kenya

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Abstract

Understanding smallholder resource allocation and trade-off in socially and ecologically dynamic agricultural production dispensation is critical for effective rural developmental interventions. Data derived from a survey of 380 smallholders in western Kenya was used to assess labour availability and to evaluate agricultural productivity in labour allocation trade-off between biomass cooking energy sourcing, agriculture, and off-farm employment. Heterogeneity in labour allocation among members and sub-counties were observed. On average leisure accounted for 80 percent of total household time, A three-stage regression showed that maize yield was significantly ($p<0.05$) influenced by the farmers' age, environmental factors, and the number of trees planted. A recommendation for improvement of rural enterprise profitability to enhance efficiency in labour allocation is provided.

Keywords: Poverty, smallholding rural-employment, developing countries