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Presented by

Hillary Kipkoech KORIR

TITLE: ENERGY ACCESS AND IMPACT ANALYSIS OF BIOGAS HARNESSING ON MAU FOREST CONSERVATION

Defended on 02/09/2019 Before the Following Committee:

Chair	Bachir Redouane	Prof.	University of Tlemcen
Supervisor	John Githiri	Dr.	Jomo Kenyatta University
External Examiner	Hassan Qudrat-Ullah	Prof.	York University
Internal Examiner	Souhila Bensmaine	Dr.	University of Tlemcen

Declaration of authorship

I state and declare that this thesis was prepared by me and that no means or sources have been used, except those, which I cited and listed in the References section. The thesis is in compliance with the rules of good practice in scientific research of Pan- African University Institute of Water and Energy including Climate Change (PAUWES).

Hillary Korir

Signature Date: 04 September, 2019

This thesis has been submitted for examination with our approval as the University Supervisor

Dr. John Gitonga Githiri,

Associate Professor, Jomo Kenyatta University of Agriculture and Technology

Signature Date: 04 September, 2019

Dedication

This study is dedicated to the residents of South West Mau forest who welcomed me to their community and shared their views towards my research. Also, to my parents and siblings who motivated me to keep working hard.

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Abbreviations and acronyms

AFREC:	African Energy Commission
BAU:	Business as Usual
BSP:	Biogas Support Program
ESMAP:	Energy Sector Management Assistance Program
FAO:	Food Agriculture Organization
GACC:	Global Alliance for Cookstoves
GCF :	Green Climate Fund
HIT:	Hedera Impact Tool kit
IPCC:	Intergovernmental panel on Climate change
DoE:	Department of Energy
IEA:	International Energy Agency
IFAD:	International Fund for Agricultural Development
IRENA:	International Renewable Energy Agency
ISLA:	Initiative for Sustainable Landscape
KENAFF:	Kenya National Farmers Federation
KENDBIP:	Kenya National Domestic Biogas Program
KENFAPP:	Kenya National Federation of Agricultural Producers
KFWG :	Kenya Forest Working Group
KSHs:	Kenya Shillings
USD:	United States Dollar
LEAP:	Long Range Alternative Planning
MoEP:	Ministry of Energy and Petroleum
MFC :	Mau Forest Complex

Mt:	Metric Tones
MTF :	Multi- Tier Framework
OECD:	Organization for Economic Co-operation and Development
REA :	Rural electrification Agency
REA:	Rural Electrification Authority
SE4ALL:	Decade for Sustainable Energy for All
SEI:	Stockholm Environment Institute
KNBS:	Kenya national Bureau of Statistics
GDP:	Gross Domestic Product
LPG:	Liquified Petroleum Gas
SPSS:	Statistical Package for Social Sciences
SWM :	South West Mau
TED:	Technology Environment Database
UN:	United Nations
UNDP:	United Nations Development Program
UNESCO:	United Nations Education, Scientific and Cultural Organization
UNIDO :	United Nations Industrial Development Organization
UNIDO:	United Nations Industrial Development Organizations

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ABSTRACT

Forests as a source of energy are important in many countries, especially in rural areas in the sub-Saharan African countries, where the availability of wood fuel is literally a human necessity for survival. These countries rely heavily on wood as a source of energy, especially for heating and cooking, and most of them are struggling to maintain their forests in the face of increasing populations and weak economies. The Mau Forest Complex sits within Kenya's Rift Valley and is the largest indigenous montane forest in East Africa but human activity including; agriculture, logging, and settlements, has reduced the Mau Forest to a quarter of what it once was, disrupting the forest's role in storing and distributing water to outlying areas. This study aimed at evaluating energy access and the impact of biogas harnessing for home cooking on Mau forest conservation and on communities living next to the forest, then to propose appropriate recommendation. Area of study was on south western Mau, where data collections was done in regions of; Chebangang, Nyangores, Londiani and Olenguruone. Data collection was facilitated using Hedera toolkit app with inbuilt questionnaire. The results obtained were generalized to represent the whole Mau Complex. Electricity sources and cooking fuels were evaluated using multi-tier framework methodology. Electricity sources used by 90 % of the population were categorized in tier 1 while cooking fuels used by 37.6% of the population were categorized in tier 1 and tier 2. Knowledge of biogas technology was found be very low, where only 24% of the population are knowledgeable. With Pearson coefficient of 0.85, relationship of education level and choice of cook stove was concluded to be independent. Analyzing energy demand in the region based on Business-As-Usual scenario (BAU), cooking energy demand will triple by the year 2040, and fuelwood will remain primary cooking fuel thus putting pressure on forest resource. It was concluded that adoption of biogas technology in the region will promote livestock intensification program and it will reduce by half fuelwood use by household. It was recommended that priority should be given to awareness campaigns on modern cook stoves and biogas technology in the region. County governments, national government ministries in charge of rural electrification and non-governmental organizations in the region should be the major stakeholders in creating awareness.

Keywords: Multi-tier Framework, Biogas technology, Energy demand, LEAP

RÉSUMÉ

Les forêts en tant que source d'énergie sont importantes dans de nombreux pays, en particulier dans les zones rurales des pays d'Afrique subsaharienne, où la disponibilité du bois de chauffage est littéralement une nécessité humaine pour survivre. Ces pays dépendent fortement du bois comme source d'énergie, en particulier pour le chauffage et la cuisine, et la plupart d'entre eux luttent pour maintenir leurs forêts face à la croissance démographique et à la faiblesse de l'économie. Le complexe forestier de Mau se trouve dans la vallée du Rift au Kenya et est la plus grande forêt montagnarde indigène d'Afrique de l'Est, mais l'activité humaine, y compris l'agriculture, l'exploitation forestière et les établissements humains, a réduit la forêt de Mau au quart de ce qu'elle était autrefois, perturbant le rôle de la forêt dans le stockage et la distribution de l'eau aux zones éloignées. Cette étude visait à évaluer l'accès à l'énergie et l'impact de l'exploitation du biogaz pour la cuisine domestique sur la conservation de la forêt Mau et sur les communautés vivant à proximité de la forêt, puis à proposer des recommandations appropriées. La zone d'étude se situait au sud-ouest de Mau, où les données ont été recueillies dans les régions de Chebangangang, Nyangores, Londiani et Olenguruone. La collecte des données a été facilitée à l'aide de l'application Hedera toolkit avec questionnaire intégré. Les résultats obtenus ont été généralisés pour représenter l'ensemble du complexe de Mau. Les sources d'électricité et les combustibles de cuisson ont été évalués à l'aide d'une méthodologie-cadre à plusieurs niveaux. Les sources d'électricité utilisées par 90 % de la population ont été classées dans la catégorie 1, tandis que les combustibles de cuisson utilisés par 37,6 % de la population ont été classés dans les catégories 1 et 2. La connaissance de la technologie du biogaz s'est révélée très faible, où seulement 24 % de la population est bien informée. Avec un coefficient de Pearson de 0,85, on a conclu que la relation entre le niveau de scolarité et le choix du fourneau était indépendante. Si l'on analyse la demande d'énergie dans la région sur la base du scénario de statu quo, la demande d'énergie de cuisson triplera d'ici à 2040 et le bois de feu restera le principal combustible de cuisson, exerçant ainsi une pression sur les ressources forestières. Il a été conclu que l'adoption de la technologie du biogaz dans la région favorisera le programme d'intensification du bétail et réduira de moitié la consommation de bois de chauffage par les ménages. Il a été recommandé de donner la priorité aux campagnes de sensibilisation sur les cuisinières modernes et la technologie du biogaz dans la région. Les gouvernements des comtés, les ministères nationaux chargés de l'électrification rurale et les organisations non gouvernementales de la région devraient être les principaux acteurs de la sensibilisation.

Mots-clés : Cadre à plusieurs niveaux, technologie du biogaz, demande énergétique, LEAP

1 INTRODUCTION

Forests as a source of energy are important in many countries, especially in rural areas in the sub-Saharan African countries, where the availability of wood fuel is literally a human necessity for survival. These countries rely heavily on wood as a source of energy, especially for heating and cooking, and most of them are struggling to maintain their forests in the face of increasing populations and weak economies. Forest is also a major source of hydropower as it serves as water catchment area also it helps to mitigate climate change by absorbing and storing carbon.

Firewood for cooking is used by millions of people daily, (Katuwal and Bohara, 2009) estimated that the average house hold uses about 3 metric tons (6600lbs) of firewood and 576 kg (1270lbs) of dung annually subsequently releasing 4.5 metric tons of CO2 emission into the atmosphere. (Osei, 1993) explained that the consumption of firewood as a source of fuel is responsible for about 54% of the deforestation in developing countries.

The Mau Forest Complex sits within Kenya's Rift Valley and is the largest indigenous montane forest in East Africa. It serves as a critical water catchment area for the country and is the source from which numerous rivers flow, and which have hydropower potential. It also acts as a natural water tower for Kenya, storing water during the rainy season and releasing it during the dry season. But human activity including; agriculture, logging, and settlements, has reduced the Mau Forest to a quarter of what it once was, disrupting the forest's role in storing and distributing water to outlying areas.

The rivers that flow from the forest are drying up, and as they disappear, so too have Kenya's harvests (and food security), its cattle and other livestock farms, its hydro-electricity, its tea industry, its lakes and even its famous wildlife parks. The finger of blame is being pointed at the settlers in Mau. And the solution, according to a special task force appointed by Prime Minister Raila Odinga, is to uproot the invaders and replant the trees. This is a hostile solution as the settlers have genuine title deeds and are the rightful owners of the lands bordering the forest. This calls for a need to find alternative solutions that will involve the communities in conserving the forest rather that chasing them away.

Biogas is alternative or substitute energy sources. As viable eco-friendly alternative technology, it can substitute firewood for cooking, heating fuel and kerosene for lighting. So, it reduces the dependency on forests and increases greenery leading to an improved environment. Biogas being a product of animal refuses and plant residues that are available to farming communities, in general, and also being a source of energy, has wider socio-cultural implications, particularly for women and children. It has many other direct and indirect impacts too.

Biogas, scientifically, is naturally produced from anaerobic fermentation of biomass and solid wastes. Biogas contains 50-70% methane, and 30-50% carbon dioxide, depending on the substrate input, and smaller amounts of other gases. At the household level, cattle, pig, and poultry excreta can be fed into small recovery systems that produce biogas for cooking, heating, lighting, or electricity generation. A small household biogas plant of 6 -10 m3 requires at least 20 kg of dung daily or three head of stall-fed cattle or six adult pigs to meet a family's basic cooking and lighting needs.

1.1 Statement of Problem

Mau forest used to cover 400 thousand hectares, but 100 thousand of these have been expropriated. The loss of forest cover has been caused by a number of factors: degradation, settlement (both legal and illegal), urbanization, unsustainable extraction of timber and forest products, lack of land use policy, and corruption, among others. (Nabutola, 2010)

The communities who settled into the forests have, over the years made it their home and source of livelihood. They cut the trees and utilize them for a living. They need it for wood fuel, charcoal selling to the cities and towns and for construction purposes. One of the solutions to these, according to a special task force appointed by Prime Minister Raila Odinga, is to uproot the invaders and replant the trees. This decision was faced by serious opposition from Rift valley leaders who saw the solution proposed as a reckless displacement of population before crafting a compensation plan or an alternative settlement scheme for squatters. Of 20,000 families living in the forest, it is estimated that about 1,962 have genuine title deeds.

The lasting solution to conserve the forest is still pending, yet the daily needs of the communities in terms of cooking and charcoal for sale, has to be met by the forest. This calls for need to explore alternative solutions that will solve the daily energy needs of the communities, like biogas harnessing, hence offsetting dependence on the forest.

1.2 Research Question

Does harnessing of biogas by communities living next to MAU forest contribute to conservation of forest and improved living standards?

1.3 Research Hypothesis

Biogas harnessing will improve living standards of the communities living next to MAU forest and contribute slightly towards conservation of the forest.

1.4 Primary Objectives

Evaluate the impact of biogas harnessing for home cooking on MAU forest conservation and on communities living next to the forest.

1.5 Specific Objectives

1. To assess rate of electricity access by communities neighbouring MAU forest.
2. To assess the use of firewood and charcoal for home use by the communities living next to MAU forest.
3. To evaluate social, technical and economic visibility of biogas technology in southern rift region of MAU forest.
4. To evaluate correlation between adoption biogas technology and consumption of firewood and charcoal in southern rift region of MAU forest.
5. To propose recommendation.

2 LITERATURE REVIEW

2.1 Introduction

Forest resources in our country are valuable natural endowment that must be sustainably managed for present and future generations. Forest resources offer a range of benefits and opportunities for local and national economic development, improved livelihoods and provision of environmental goods and services such as watershed protection and carbon sequestration. ((Ministry of Environment, 2014)

Over 80% of Kenyans rely on wood biomass for their energy requirements, which exerts considerable pressure on the tree and forest resources. In addition, the wood conversion technologies for timber manufacturing and charcoal production are obsolete and wasteful leading to overharvesting of trees to meet the demand.(Ministry of Environment, 2014)

As pointed out by (Ikonya, 2018), non-wood forest products are important to the livelihoods of the rural communities and account for a significant share of household incomes and expenditures. Some of the non-wood forest products that contribute to sustainable livelihoods include gums and resins, honey, essential oils, frankincense, myrrh, fibers, medicinal and aromatic plants, dying and tanning materials. In addition, many of these products have high potential for export. In times of food scarcity, some non-wood products are the main source of nutrition for many communities. Agriculture has a dual role as an energy user and as energy supplier in the form of bio energy (FAO, 2000). In most developing countries, energy for cooking consumes more energy than any other single activity (Practical Action 2012). According to IEA (2011), over 90% of household energy needs in many developing countries, especially in rural areas, are met by biomass, such as fuelwood, charcoal, agricultural waste and animal dung, supporting over 2.5 billion people. What is more worrying, is that the absolute number of persons particularly in Africa and Asia using solid fuels, is increasing even though figures reveal that the proportion of households relying mainly on solid fuels for cooking has decreased world-wide, from 62% in 1980 to 41% in 2010 (Bonjour et al., 2013).

“A report on World Energy Outlook by the International Energy Agency (IEA 2011) clearly stated that the world today faces a significant energy divide; between rich and poor countries. It further indicated that more than 95% of the world’s population without access to electricity and clean cooking facilities live in sub-Saharan Africa and developing Asia. It is against such backdrop that Organization for Economic Cooperation and Development (OECD) and IEA (2006) reports indicated that in the absence of new policies, the number of people relying on biomass would increase to over 2.6 billion by 2015, and to 2.7 billion by 2030 because of population growth." (Ikonya, 2018)

Table 2-1. The trend and projection on use of biomass in different regions.

Region	**2004**	**2015**	**2030**
TOTAL (In millions)	2527	2640	2727
Sub-Saharan Africa	22.75%	23.75%)	26.41%
North Africa	0.16%	0.19%	0.18%
India	29.28%	29.43%	28.68%
China	19%	17.16%	14.45%
Indonesia	6.17%	6.48%	6.60%
Rest of Asia	19.35%	19.73%	20.57%
Brazil	0.91%	0.98%	0.99%
Rest of Latin America	2.37%	2.28%	2.13%

Source: OECD and IEA (2006)

In the reference scenario, as presented in the table above, where no new policies are introduced, the number of people relying on traditional Biomass rises from 2.5 billion in 2004 to 2.6 billion in 2015 and to 2.7 billion in 2030. The UN projections (recommendation of the United Nations Millennium) targeted 1.3 billion people switching to other sources of fuel by 2015 (UN 2010).

"Ban Ki-moon, the Secretary-General of the United Nations, in his address, (A vision statement on sustainable energy for all (Ki Moon, 2011) lamented the continued emissions of carbon dioxide and other greenhouse gases from fossil fuels that contribute to changes in the Earth's climate. The UN with its many organizations, Global Tracking Framework, United Nations Development Program (UNDP); The United Nations Industrial Development Organization (UNIDO) The United Nations Educational, Scientific and Cultural Organization (UNESCO) that are member organizations of UN Energy undertake several initiatives involved in efforts that support the decade 2014-2024 as the Decade of Sustainable Energy for All. These include among others; Clean Start-a programme that supports access for lowincome households and micro-entrepreneurs to modern energy through microfinance - designed to support at least 2.5 million people by 2017." (Ikonya, 2018)

By using renewable resources and non-polluting technology, biogas generation serves a triple function: waste removal, environmental management and energy production (IFAD 2012). Further Langeni et al., (2010), suggests that each household can realise up to US$ 724 by replacing wood use with biogas, apart from other positive impacts to the environment. It also includes carbon (credit) finance that could therefore be used to cover part or all of the costs.

According to Bajgain & Shakya (2005), in Nepal, it is estimated that each installation avoids 4.6Mt CO2 e/year (the amount in Metric tonnes, of carbon dioxide (CO2) emitted per year). Average per capita emissions in developed regions are significantly higher than in developing regions. In developed regions, average emissions are about 11 metric tons of CO2 per person per year, compared to about 3 metric tons in developing regions (UN, 2010).

The United Nations (UN), Food and Agriculture Organization (FAO) estimates that current emissions of methane and nitrous oxide from manure of domesticated animals are responsible for about 6% of man-made greenhouse gas emissions (FAO, 2006). Many researchers attest that collecting and controlling animal manure reposes a great potential for reduction of greenhouse gas emissions (O'Mara 2004, and Steinfeld et al., 2006). The greatest potential for using livestock as a renewable energy source lies in small-scale mixed farm systems where farmers can create synergies, for example by feeding animals crop residues and using animal manure to fertilize crops (IFAD, 2012). Manure-based biogas digester systems are considered ecologically friendly since the technology captures and utilizes methane directly, thereby limiting total greenhouse gas emissions from livestock (IFAD, 2012).

The mere ownership of at least two cows can warrant biogas installation as the dung from the two cows typically suffices to meet the cooking requirements of a household. According to UN (2010), this has made the technology relevant in some rural and peri--urban settings but more particularly in south Asia and Africa where animals roam freely.

One primary reason for lack of widespread use of biogas around the world is the high initial investment for putting in a biogas facility and a steady supply of animal manure. The other reason is the low investment for despite year-over-year growth in global clean energy capacity, global investment in clean energy in 2016 declined by 18% from 2015 21 to $288 billion (down from $349 billion in 2015). Worldwide, wind and solar continued to experience the highest levels of new investment of all renewable technologies in 2016 (91% of all asset classes). Even so, there are many biogas plants in use around the world; 42.8 million in China and 4.4 million in India alone (GACC, 2014). Hivos (2013) attributes the successful Biogas Programme (BPII) in Vietnam and the Biogas Support Programme (BSP) in Nepal to the 'multi-stakeholders sector development approach'. However, much more is required to achieve the Sustainable Energy for All initiative goals by the year 2030 (IEA/ World Outlook, 2015).

The uptake of biogas technology had remained bumpy since it was the introduced into Kenya in the mid-1950s. It was not until the Kenya National Domestic Biogas Programme (KENDBIP) set up by the Kenya National Federation of Agriculture Producers (KENFAP), currently Kenya National Farmers Federation (KENAFF), rolled out a biogas programme in 2010 that Biogas gained some impetus (Ngugi, 2007).

Between the years 2009 to the end of 2013 in a programme called Phase 1 phase (2009- 2013) KENDBIP, they targeted dissemination of 8,000 domestic biogas plants. Due to renewed interest in the adoption of biogas technology and other alternative forms of energy among rural households in Kenya, a total of 11,579 biogas plants were installed in the country against a target of 11,690 plants. This target was revised upwards after the first 2 successful years of implementation, representing 99% target achievement.

Another milestone in the biogas technology industry in Kenya has been the introduction of plastic digesters. This has provided the market with alternative digester design options which significantly improve the biogas credit landscape. It is explicable that potential biogas credit providers prefer financing of plastic bio-digesters which are movable, as opposed to the masonry fixed dome plants due to the fact that these plants serve as security to the loan. As a result in 2014, the plastic digesters accounted for 466 plants out of 2533 installed during the year representing 18% market share in their first year in the market (KENDIP 2014).

2.2 Theoretical Review

"Biogas plants capture gas (methane and carbon dioxide) released from animal manure for use as a household fuel for cooking and lighting (Hazra, et al., 2014). The majority of existing biogas is produced using anaerobic digesters, gas-tight high-moisture enclosures that provide a stable environment for methane-producing bacteria to flourish. In the biogas, dung is inserted through an inlet into a sealed mixing pit, where biogas is generated through anaerobic digestion (Hazra, et al., 2014). The raw biogas is collected from the digester and then flared or processed and used in energy applications as a replacement for electricity, natural gas, propane, diesel fuel, or gasoline (Teodorita et al., 2008). After digestion the slurry released from the plant is often used as an agricultural fertilizer. 13 Biogas can be compressed, much like natural gas, and used to power motor vehicles." (Ikonya, 2018)

Biogas can also be cleaned and upgraded to natural gas standards when it becomes bio-methane (Biogas World 2016).

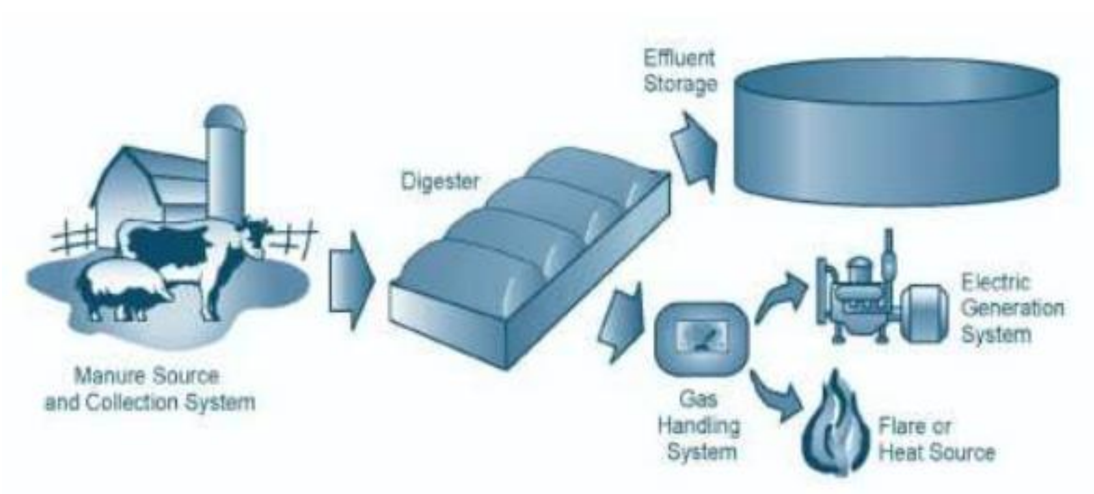


Figure 2-1: Biogas Schematic, Source: U.S. Environmental Protection Agency, EPA, (2014)

2.3 A multi-dimensional approach for assessing energy access: The Multi-Tier Framework

Defining the concept and measurement of access to energy is of great importance to governments and development agencies in order to design and adapt the appropriate policies and programs to achieve the objectives of energy supply for the population. The Sustainable Energy for All initiative (SE4All) launched by the Secretary General of the United Nations in 2011 aims to achieve universal access to modern energy services by 2030. The Sustainable Development Goal 7 (SDG7), adopted in 2015 by all nations, explicitly aims to achieve access to affordable, safe, sustainable and modern energy for all by 2030. According to the Tracking SDG7: The Energy Progress Report de 2019, worldwide, it is estimated that more than two billion people lack access to modern energy (grid connection and/or clean and safe fuel for cooking).

To monitor progress towards the goals of energy access for all, the global and multi-donor technical assistance trust fund, the Energy Sector Management Assistance Program (ESMAP) of the World Bank and the International Energy Agency have led a consortium of 23 international agencies to establish the Global Monitoring Framework of the SE4All (Global Track Framework - GTF). It describes how to measure the baseline and progress towards the goals of the SE4All by collecting energy data with regularity. ESMAP, in the framework of the SE4ALL initiative, and in consultation with multiple development partners, has developed the Multi-Tier Framework (MTF) to monitor and evaluate access to energy following a multidimensional methodology to define both the concept of energy and the parameters for its measurement and monitoring.

Traditionally, access to energy has been measured in a binary way: connected or not connected, cooking with biomass or not. However, these metrics overlook the quality of the connection, such as the capacity of other technologies to provide energy, such as home solar systems or mini-grids.

The need of a multidimensional assessment brought to the definition of the Multi-Tier Framework (MTF), launched by The World Bank in 2015, with the explicit objective to become the new global measurement standard (in each country) for define and monitor the goals of electrification programs, and highlight the most important challenges to improve access to affordable, reliable and safe energy. For this new methodology, ESMAP has designed a detailed global survey to monitor access to energy at various levels. The main objectives of the survey are:

- To establish a global baseline of access to energy, according to the multidimensional definition of the MTF approach;
- To transfer capacity to national statistical offices to track progress towards the goals of SE4ALL and the SDGs in the future;
- To continue to improve the tools and capabilities to track progress towards the SE4ALL goal of universal access to modern energy services by the year 2030, based on MTF;
- To provide reliable data on the energy sector that can meet the needs of multiple stakeholders, including government, regulators, public services, project developers, civil society organizations, development agencies, financial institutions, appliance manufacturers, international programs, and academia.

Through detailed household surveys, the collected information allows to answer the main questions related to energy access: how many lacks adequate access to energy, how many need to improve access, and what measures will be taken. In this way, the development of the MTF and the methodology represent a milestone for the sector that should be the basis and language for all actors, not only for quantifying, but also for monitoring the progress of access to energy for all.

2.3.1 A multidimensional, definition of access to energy

The MTF redefines the access to energy from traditional binary accounting (connected or not connected, cooking with firewood or not) to a multidimensional definition such as the ability to take advantage of adequate energy, available when necessary, reliable, good quality, convenient, affordable, legal, healthy and safe for all required energy services.

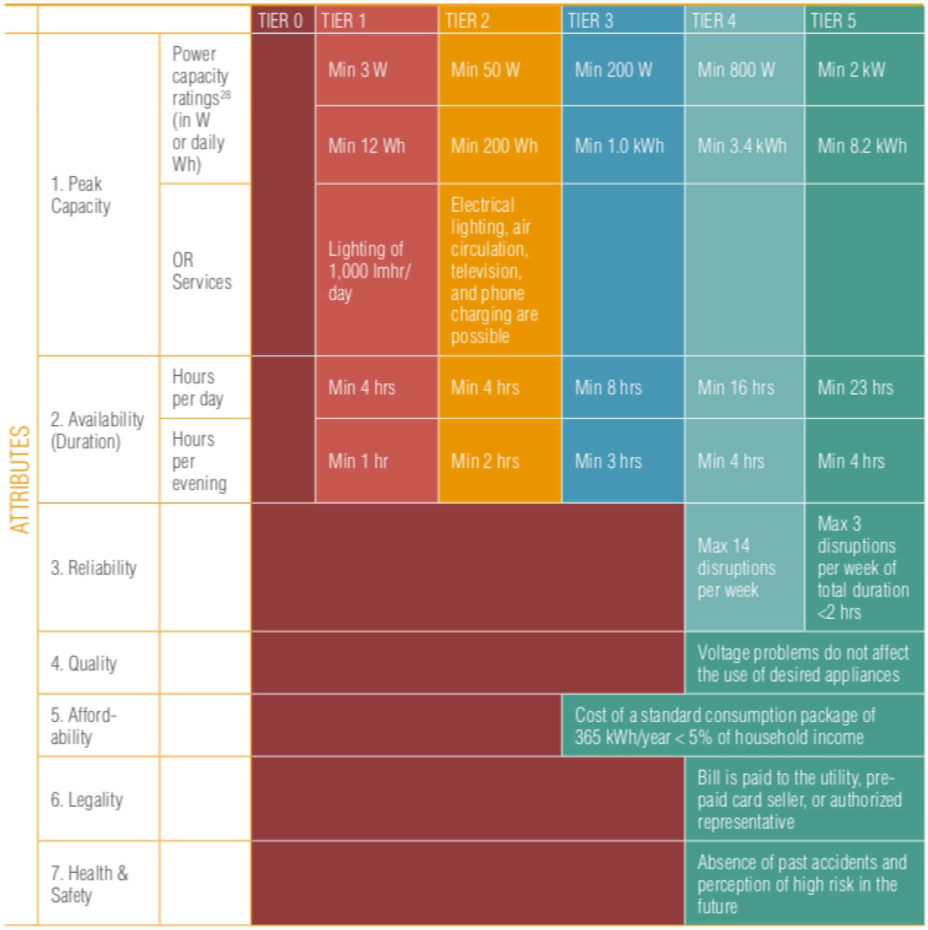
That is, having an electrical connection does not necessarily mean having access to electricity according to the new definition, but it also takes into account other aspects, such as, for example, reliability, affordability, among other attributes. Thus, access to energy is measured in the spectrum of levels, from Level 0 (tier 0) (without access) to Level 5 (tier5) (the highest level of access).

2.3.2 Ranking matrix to evaluate household energy access

Access to electricity is measured based on standards (attributes) of multiple levels, independent from the energy technology. The successive thresholds of these attributes that are associated with the supply, allow a greater use of electrical appliances. The relevant attributes to evaluate the electricity of the households estimated by the MTF methodology are:

- **Capacity:** What appliances can the household use?
- **Duration (including daily supply and night supply):** Is the power source available when the household needs it?
- **Reliability:** Is electricity service interrupted frequently?
- **Quality:** Does the fluctuation of the voltage damage the appliances?
- **Affordability:** Can the household afford to buy the minimum amount of electricity?
- **Legality:** Is the service provided formally or informally?
- **Health and Safety:** Is it safe to use electricity service or are the household members risking your health if you use the service?

Each attribute is evaluated separately and the general level for household access to electricity is calculated by applying the lowest level obtained in any of the attributes. That is, the attribute with the lowest rating determines the household energy access level (tier).



ATTRIBUTES		TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
1. Peak Capacity	Power capacity ratings[28] (in W or daily Wh)		Min 3 W	Min 50 W	Min 200 W	Min 800 W	Min 2 kW
			Min 12 Wh	Min 200 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 kWh
	OR Services		Lighting of 1,000 lmhr/day	Electrical lighting, air circulation, television, and phone charging are possible			
2. Availability (Duration)	Hours per day		Min 4 hrs	Min 4 hrs	Min 8 hrs	Min 16 hrs	Min 23 hrs
	Hours per evening		Min 1 hr	Min 2 hrs	Min 3 hrs	Min 4 hrs	Min 4 hrs
3. Reliability						Max 14 disruptions per week	Max 3 disruptions per week of total duration <2 hrs
4. Quality						Voltage problems do not affect the use of desired appliances	
5. Affordability					Cost of a standard consumption package of 365 kWh/year < 5% of household income		
6. Legality						Bill is paid to the utility, pre-paid card seller, or authorized representative	
7. Health & Safety						Absence of past accidents and perception of high risk in the future	

Figure 2-2 : Ranking matrix to evaluate household energy access.

2.3.3 Ranking matrix to evaluate access to energy services

The MTF methodology defines a separate framework for measuring access to electricity services. A gradual improvement of the electricity supply allows greater and better access to different appliances for different needs. Thus, in a second matrix that measures access to electricity services, the categorization is according to the type of appliances used in the home. A household may obtain ratings at different levels through access to electricity supply and access to electricity services, reflecting the availability of appliances despite poor supply or inability to purchase appliances (or high consumption) of electricity) despite the adequate supply.

	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Tier criteria		Task lighting AND Phone charging	General lighting AND Phone Charging AND Television AND Fan (if needed)	Tier 2 AND Any medium-power appliances	Tier 3 AND Any high-power appliances	Tier 2 AND Any very high-power appliances

Figure 2-3 : Ranking matrix that evaluates energy access based on household appliances.

2.3.4 Ranking matrix to evaluate access to modern cooking solutions

The multi-level framework for measuring access to cooking energy is based on seven attributes: (i) health (based on indoor air pollution), (ii) convenience (based on fuel collection time and stove preparation time), (iii) safety, (iv) affordability (including spending on stoves and fuel), (v) efficiency, (vi) quality and (vii) availability. In this methodology, a cooking system refers to the combination of a stove and a type of cooking fuel. A cooking system includes all the cooking solutions that are used, as well as the place of cooking and ventilation.

Data on access to cooking energy such as ventilation, the quality of the fuel used, convenience, availability and affordability can be collected through household surveys. Other parameters, such as indoor air quality and efficiency, can be better measured through supply side data based on laboratory tests or estimation based on mathematical models.

- **Affordability:** Can the household pay for both the kitchen and the fuel?
- **Convenience:** How long does it take the household to get and prepare fuel and cooking before a person in the household can cook?
- **Availability:** Is the fuel available when the home needs it to cook?
- **Quality:** Does the quality of the fuel affect cooking?
- **Security:** Is it safe to use the kitchen or is the person exposed to possible accidents? Have accidents occurred in the past due to the use of fuel?

The standards for the measurement of multiple attributes to describe access to cooking systems of households are summarized in the following table. The lowest level among all the attributes determines the general access to the kitchen level for the home.

Figure 2-4: Ranking Matrix to evaluate modern cooking solutions

2.4 Leap Software

The software LEAP (Long Range Alternative planning) was developed by Stockholm Environment Institute (SEI). It is employed to Assess the energy development policies (Leap ,2011). LEAP is an end use of scenario analysis and its structure is showing below:

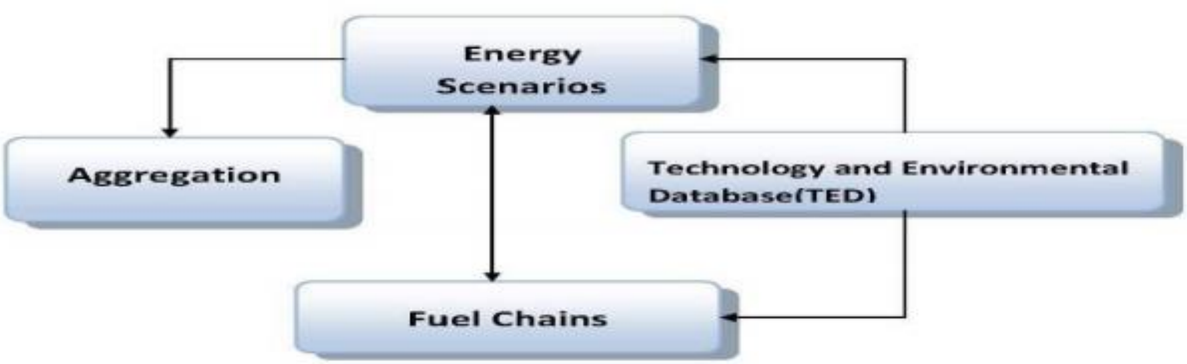


Figure 2-5 : LEAP software structure

Energy scenario is the main component < heart > of the LEAP software and it shows how future energy system might evolve over time under particular set of policies. Technology and Environment Database (TED) concerns more the compilation of Technical considerations, cost and environmental data for the range of energy technologies from types of sources including the International Energy Agency (IEA), Department of Energy (DoE) and the Intergovernmental Panel on Climate Change (IPCC). The fuel chain used to compare and asses total Energy and environmental impacts of the specific fuels and technology choices per unit of energy, for service delivered and end the aggregation program which is used to display multi area results from analyses carried out in different modules of the program. LEAP is more useful and specifically appropriate to the modelling of energy systems which consider historical macro-economic data (top-down) for trend analysis and/or short- run development issues. Indeed, initial input data required by LEAP is very low only the base year require detailed statistical data. Looking at the lack of quality time series data in most African countries, the LEAP software appears as a good option.

The LEAP framework is disaggregated into hierarchical tree structure of four levels: Sector, Subsector, End- use and appliances. Its accounting platform matches demand with supply side energy technology outputs, while the scenario manager facilitates the comparison of alternative electricity generation systems over the medium to long term duration to enable technical, economic and environmental impact analysis.

2.5 Kenya rural energy policy and Targets

According to data from MoEP (REA, 2015), biomass provides about 69% of the country's overall energy requirements while petroleum accounts for about 22% and electricity about 9%. As at December, 2014, 69% of the electricity component was generated using renewable energy sources with fossil fuels providing the balance of 31%.

There is a gap between the existing tree cover vis-a-vis the minimum constitutional requirement of 10%. The continuous overreliance of Biomass as a primary source of energy threatens achievement of this requirement.

Biomass fuels are the largest source of primary energy in Kenya with wood-fuel (firewood and charcoal) accounting for about 69% of the total primary energy consumption. About 55% of this is derived from farmlands in the form of woody biomass as well as crop residue and animal waste and the remaining 45% is derived from forests.

Wood fuel supply management is crucial to ensure sustainable supply to meet the growing demand. Key issues here include: competing land use activities, the growing imbalance between supply and demand and the attendant adverse environmental as well as related land and tree tenure issues, among others. (REA policy, 2015)

In an effort to minimize overreliance on biomass the government has put in place incentives to promote the use of Biogas. A feasibility study carried out under this initiative established that it is possible to construct 6,500 biogas digesters in Kenya every 5 years. Several biogas projects are being undertaken by MoEP and REA in public institutions. The private sector is also implementing a number of similar initiatives all over the country. (REA policy, 2015)

As discussed in the Kenya energy policy document of 2015, the following challenges are faced in the uptake of bio-gas technology;

1. Lack of awareness on the potential and benefits of biogas technology.

2. Inadequate RD&D on biogas technologies.

3. High upfront costs of domestic and commercial biogas plant and equipment.

4. Inadequate capacity and skilled biogas contractors in the country.

5. Insufficient legal and regulatory framework for biogas contracts.

In order to address these challenges in short, medium and long term, MoEP in collaboration with REA has rolled out Policies and Strategies. The short term will be period between 2015-2019, medium term 2015-2019 and long term 2015-2030. These policies and strategies are;

1. Develop and implement public awareness programs on the benefits and potential of biogas technology.

2. Undertake and promote RD&D of biogas energy technologies.

3. Provide appropriate fiscal incentives for local manufacture of biogas plant and equipment, large scale production, storage and distribution.

4. The government to initiate capacity building programs on biogas technology in learning institutions.

5. The government to develop and enforce legal and regulatory requirements on biogas.

6. Support domestic and community-based biogas plants among urban, rural population and institutions.

7. Promote the use of biogas as an alternative to woodfuel and kerosene for domestic and commercial energy needs.

3 METHODOLOGY

At 400,000 hectares, the Mau Forest Complex forms the largest forest block in the country, and the largest single block of closed-canopy forest in East Africa. Forests that constitute the complex include Transmara, Ol Posimoru, Maasai Mau, Eastern Mau, Mau Narok, South West Mau, Western Mau, Mt. Londiani, Eburru, Molo and South Molo. The northern part comprises Tinderet, Northern Tinderet, Timboroa, Nabkoi, Kilombe Hill, Metkei, Maji Mazuri, Chemorogok and Lembus forests. The Mau Forest Complex is one of the five water towers in Kenya, providing the upper catchments of many major rivers, including Nzoia, Yala, Nyando, Sondu, Mara, Kerio, Molo, Ewaso Ngiro, Njoro, Nderit, Makalia, and Naishi. These rivers in turn feed major lakes, including Natron, Victoria, Turkana, Baringo and Nakuru.

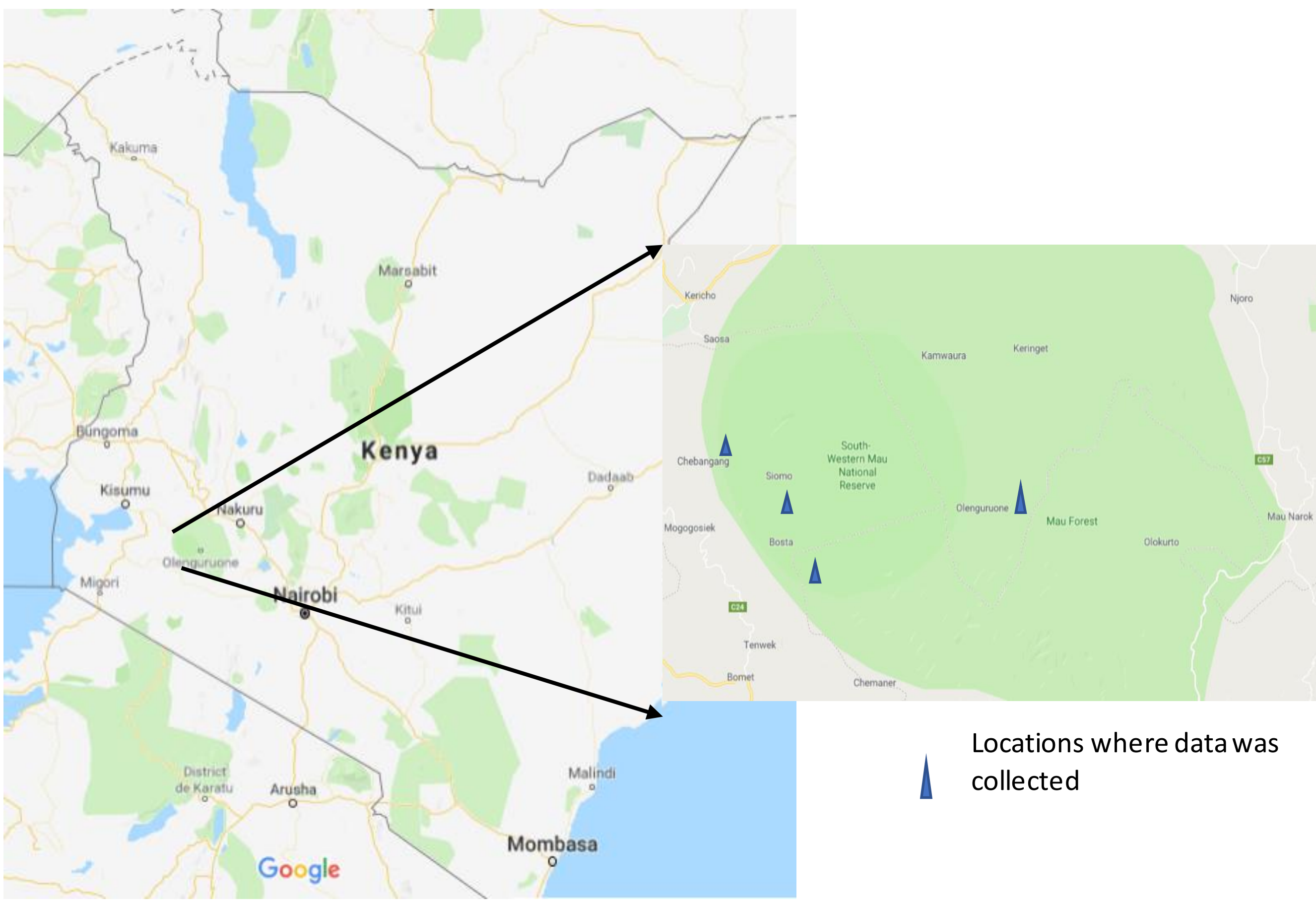


Figure 3-1: Data collection points within south west Mau Forest (SWMF)

This study was focused on south western Mau, where data collections was done in regions of; Chebangang, Ny'ongores, londiani and Olenguruone. The results obtained has been generalized to represent the whole Mau Complex.

South west Mau is located in the southern part of Kenya and has approximate size of 347,000 hectares. It is bordered by several communities; Londiani ward to the north with approximate population of 28,139, Chebangang in Kimulot ward towards the south east with approximate population of 22,735, Nyangores ward to the south with approximate population of 35,420, Olenguruone in Kiptagich ward with approximate population of 24,750.

3.1 Climate

South West Mau (SWM) forest reserve is the largest of all the blocks of the Mau forest complex (MFC) covering about 84000 ha; about 20% of the MFC. This forest block forms the upper catchment of River Sondu, the lifeline of Sondu Miriu hydropower plant and the major source of water for other users that include domestic, industrial and agricultural use in the Sondu catchment area. The forest is characterised by an afro-montane vegetation type (Kinyanjui, 2009) and consists of tall, broadleaved evergreen species that give way to bamboo at the higher altitudes. The forest reserve lies within 0.5° south of the equator and between 2000 m and 2800 m in altitude. The forest and its surrounding areas receive an annual rainfall ranging from 1500 mm to 2100 mm. The perennial streams emanating from this area form a critical source of water to the main Sondu River, which serves the surrounding tea estates and the densely populated lake shores of LVSCA (Edwards and Blackie, 1979). A study of the South West Mau and Eastern Mau forest reserves by UNEP/KFWG (2006) has shown South West Mau as the most deforested of all the blocks comprising the MFC and has proposed reforestation and rational land use as some of the measures needed to curb the degradation of the MFC catchments. (Kibe, 2014)

3.2 Socio-Economic activities

The Mau Forest plays an important role in the agricultural, tourism and energy sectors. The climate conditions of the area adjacent to the forest have supported the development of the cultivation of tea, one of the main national agricultural products. Maasai Mara National Reserve and Lake Nakuru National Park, two famous tourist destinations, take advantage of the rivers that pass through them and that have their sources in the Mau Forest. Finally, Kenya generates more than 44% of its energy from water and around the Mau Complex several hydro-electric power stations are operational. (Albertazzi, Bini, Lindon, & Trivellini, 2018)

The tea fields are spread in vast contiguous areas just outside the forest borders. Such concentration is not just related to the favorable farming conditions guaranteed by the Mau Forest ecosystem, but it is a colonial legacy. These areas represented the Western side of the so-called "White Highlands", the most fertile land of the country reserved to foreign settlers and close to the Uganda railway (Morgan, 1963).

3.3 Research Design

The study adopted a descriptive research design which emphasizes the measurement and analysis of relationships between variables. The selection of these designs was guided by the nature of data that was to be collected, the time available as well as the objectives of the study. Given the dynamic and urgent nature of the solid fuel challenge, the researcher had to collect first-hand information from the field. The researcher was mainly concerned with views, opinions, perceptions, feelings, and attitudes towards energy access both for lighting and cooking and also the socio-economic status of the community. This information was collected through the use of questionnaire tool.

3.4 Study population

This study focused on south western Mau, where data collections was done in regions of; Chebangang, Ny'ongores, londiani and Olenguruone. The results obtained has been generalized to represent the whole Mau Complex. This study targeted mainly farmers living adjacent to the forest. Mostly, these households have the burden of collecting and utilizing the ever-diminishing wood fuel stocks and also encroaching the forest for other economic benefits. Some of the farmers have been involved in community forest associations whose aim is to conserve the forest.

3.4.1 Sampling Procedure

The study adopted a non-probabilistic and purposive sampling, in the selection of the regions within South Western Mau to be studied. Thus, londiani and Olenguruone locations were chosen to represent regions with physical evidence of forest degradation while Chebangang and Nyangores location were chosen to represent regions where forest cover is still conserved.

Random sampling was used to target households in the selected locations in which the respondents chosen were based on their convenience and availability.

3.4.1.1 Sample Size

The researcher adopted Fisher's formula to determine the sample size;

Where,

n is sample size

$$n' = Z^2 pq \, D/d^2 \quad (1)$$

Z^2 is the confidence level taken as1.96 at 95%

p is a proportion of the targeted population estimated at 0.5 confidence level at 95%,

q is1-p,

D is design effect of 1 and,

d is level of statistical significance taken as 0.05.

$$\text{Hence, } n' = (1.96^2 * 0.5 * 0.5 * 1)/0.05^2 = 384 \quad (2)$$

N = accessible population (in this case, Londiani, Chebangang, Nyangores and Olenguruone villages has approximately 8100 households in total).

Therefore,

$$\text{Sample size, } n = 384 * 8100 / \{8100 - 1 + 384\} \quad (3)$$

= **331 households**.

This is approximately 80 households per village.

3.5 Data Collection

Both Qualitative and quantitative approaches were employed in this study. With qualitative approach, direct and indirect variables influencing energy access, were able to be gathered and analyzed in depth. Through observations and taking of pictures during interviews, researcher was able to enhance the quality of data collected.

Structured questionnaires were used to collect data from the households. The first part of the questionnaire sought to collect background data of the household like; number of people living in the household, source of income, highest education level, among others. The second part sought information on; electricity access and services, electrical appliances etc. Finally, the third part focused on; cooking solutions, health, and quality of cooking fuel.

Face to face interview was adopted while administering the questionnaire. At total of nine field assistants were trained and contracted by the researcher to assist in administering the questionnaire. This ensured large area coverage in a shorter time while improving on data collected as the data collector is not overwhelmed with work.

3.5.1 Data collection Instruments

3.5.1.1 HEDERA collect

HEDERA collect is a mobile App (Android OS) designed for capturing all relevant information at the household level, in order to efficiently assess and monitor the progress towards the Sustainable Development Goals. The first area of application of HEDERA collect is the access to energy SDG7. HEDERA collect integrates an optimized version of the detailed energy access assessment survey, tailored to microfinance institution and suitable for offline application, which allows to drastically reduce the data collection costs.

3.5.1.2 The HEDERA Impact Toolkit (HIT)

The ESMAP survey is available in English as PDF, along with the data collected in several countries.

"HEDERA has optimized the energy survey, in order to facilitate its implementation (reducing training time, automatically validating data, optimizing the logic tree), especially in the rural context. The mobile survey developed by HEDERA can be completed in less than 15 minutes, extracting all the information required for characterizing access to energy at the household level according to MTF." (Caiazzo, 2019)

Questionnaires was structured to capture; firewood use, charcoal use, knowledge of biogas technology, level of education, income generating activities, health, farming methods, and biogas programme in the area. This questionnaire was administered to households. Focused group discussion interview was structured to include; cooking fuel, biogas and environmental conservation. This case will also apply to Key informant interviews.

3.6 Data analysis

Descriptive statistics and analysis were used to analyse quantitative and qualitative data collected using the questionnaire. The study used means, standard deviation, relative frequencies and percentages to interpret the quantitative data.

Qualitative Data obtained was coded and clustered into common themes for subsequent statistical analysis. The Statistical Package for Social Sciences (SPSS) computer software was used for the analysis to generate data array used for subsequent data analysis.

To evaluate the status of firewood and charcoal usage by the communities living adjacent to the forest, data was presented using frequency tables, pie charts, cross tabulations, and histograms to indicate the distribution of background characteristics of respondents.

A stepwise linear regression analysis was carried out on the socio-cultural factors that influence choice the cooking solution. To test for correlation between social-cultural variables and modern energy access (electricity and cooking), a Pearson product Moment Correlation was generated.

Data was also analysed using the likert scale and regression analysis. This generated quantitative reports through tabulations, percentages, and measures of central tendency. Pearson's product Moment correlation test was used to evaluate the degree of relationship between adoption biogas technology and consumption of firewood and charcoal in south west Mau forest

3.7 Development of energy demand model

The statistics obtained by analysing data using SPSS, has been used as the input data in evaluating different scenarios using the LEAP software. This data has been used to develop energy demand models of the communities and has been supplemented by secondary data from trusted sources.

3.7.1 Household sector

A sample size of 330 households were interviewed over a population of approximately 8100 households in all the four villages combined out of which 216 households were administered questionnaire. Preferences were given to households living adjacent to the forest, because their energy use behaviour will directly relate to the status of forest conservation.

Table 3-1: Table showing different sources of primary electricity in South West Mau.

primary_electricity_source

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	candles	21	9.7	9.7	9.7
	firelight	18	8.3	8.3	18.1
	grid	36	16.7	16.7	34.7
	keroseneLamp	35	16.2	16.2	50.9
	shs	78	36.1	36.1	87.0
	solarLamp	21	9.7	9.7	96.8
	solarTaskLight	1	.5	.5	97.2
	solarTorch	3	1.4	1.4	98.6
	torch	3	1.4	1.4	100.0
	Total	216	100.0	100.0	

Table 3-2 : Approximately 95 % of the population use handmade cook stove as the primary stove

primary stove

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	handmade	205	94.9	94.9	94.9
	Improved Oven	1	.5	.5	95.4
	lpg	4	1.9	1.9	97.2
	Manufactured Solid,	5	2.3	2.3	99.5
	Natural Gas	1	.5	.5	100.0
	Total	216	100.0	100.0	

Table 3-3: approximately 95 % of the residents use firewood as the main cooking fuel

primary_cooking_fuel

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	biomass	1	.5	.5	.5
	firewood	205	94.9	94.9	95.4
	lpg	4	1.9	1.9	97.2
	Natural Gas	1	.5	.5	97.7
	none	5	2.3	2.3	100.0
	Total	216	100.0	100.0	

Table 3-4: 85 % of the population earn less than 100 dollars per month.

Monthly income level of the household

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	<= 10000	183	84.7	84.7	84.7
	10001 - 18000	9	4.2	4.2	88.9
	18001 - 27000	16	7.4	7.4	96.3
	27001 - 35000	2	.9	.9	97.2
	35001 - 43500	2	.9	.9	98.1
	43500- 51500	3	1.4	1.4	99.5
	51500+	1	.5	.5	100.0
	Total	216	100.0	100.0	

3.7.2 Technical and Economic feasibility assessment of the bio-digester in the region

Feedstock assessment:

Cow dung is the main feedstock for the household biogas system. The amount of biogas production per kg of cow dung was measured and estimated to be 0.023-0.04 m3 /kg (Gunter U, 2011).

With application of the average of this experimental value, the biogas production volume per cow was estimated with the following formula:

$$V_c = 0.33N_c * W_d * 365 \quad (4)$$

Where,

Vc: Volume of biogas production from cow dung (m3 /year)

Nc: Number of cows in facility

Wd: Average cow dung production in kg per cow

The value W_d is variable depending on cow conditions such as age, weight, nutrient status, etc. Here, 20 kg/cow is applied.

The volume of biogas production per person was reported to be 0.02-0.028 m3 /person/day in the experiment in Uganda (E.Menya and Y. Alokore, 2013). With application of average value of this, the amount of biogas production from human waste was estimated with the following formula:

$$V_h = 0.024N_h * O * D * R \quad (5)$$

Where,

V_h: Volume of biogas production from human waste (m3 /year)

N_h: Number of persons utilizing a toilet connected to a digester in facility

O: Body weight ratio, average weight of persons/average weight of adults

R: Toilet usage ratio (percentage of toilet use connected to the digester)

The value O depends on the persons age. For teens, 0.8 is applied while adults in adults, 1.0 is applied. The value R was estimated with assumption of how often the toilet connected with digester is used, when different types of toilets, which are not connected to a digester, are installed in a household or facility. This value is determined by interviews on situation of respective households (0.3-0.75).

3.7.2.1 Benefit analysis:

The benefit of biogas system consists of fuel wood saving and electricity saving, and can be calculated by the amount of saved fuel wood and/or electricity. Energy usage and energy demand in the household was assessed by collecting data of monthly electricity bills and amount of actual usage of fuel wood.

The benefit of fuel wood saving was calculated with the following formula:

$$S_f = \frac{(V_{cw}+V_{hw})\times C_{gas}}{\frac{C_{wood}}{E_{stove}}}, \quad B_f = S_f \times P_{wood} \tag{6}$$

Where,

S_f: Saved amount of fuel wood by biogas (tons/year)

V_{cw} and V_{hw} : Biogas volume V_c and V_h allocated for cooking fuel saving (m^3)

C_{gas}: Calorific value of produced biogas (MJ/m3)

C_{wood}: Calorific value of fuel wood (MJ/ton)

E_{stove}: Efficiency of cooking stove

B_f: Benefit of fuel wood saving (Ksh)

P_{wood}: Price of fuel wood (Ksh/ton)

Here, calorific value of produced biogas 20 MJ/m3 (M. Kaltschmittm, 2003) was applied for Cgas. The calorific value of fuel wood, Cwood, is variable depending on moisture percentage and condition of wood. For dry wood, the value is indicated to be 19.0-22.5 MJ/Kg (Hubbard W., et al., 2007). The value of 20.0 is applied in this study. Estove value depends on the actual cooking stove type that the household uses, and 10% (N.Shrestha, 2001) is applied for Estove here. Fuel wood price, Pwood, is also variable depending on local condition, and was set to be 3,300 kSh/ton from local interviews.

System design:

The size of digester was determined with the following formula (Gunter U et al., 2011 and Martin G et al, 2012)

$$V_{dc} = 1.89 \times N_c, V_{dh} = 0.1 \times N_h \quad (7)$$

Where,

Vdc: Volume of cow dung digester (m3)

Vdh: Volume of human waste digester (m3)

3.7.3 Development of the energy demand model

The energy consumption profiles are based on the survey data collected.

So total consumption for each fuel by energy service is calculated as:

$$T = N * pe * pf * E \quad (8)$$

where

N- Number of households in sub-category (electrified or non- electrified)

pe- Percentage (%) of households that use energy service

pf- Percentage (%) of households that use fuel (e.g. firewood) (based on survey data) for energy service (e.g. cooking) (based on survey data)

E- Energy intensity per energy service (based on bottom up calculation of appliance ratings and hours of usage, and calibrated to meet total sample consumption estimate from survey data)

3.7.4 Energy Demand

In this case focus is given to average energy demands per household per year. Both for lighting and cooking. This is based on survey carried out in the study area.

Table 3-5: Final Energy intensity per household in South West Mau forest

	Consumption by household per year
Firewood	920 kg
Charcoal	180 kg
LPG	36 kg
Electricity for lighting	252 kwh
Solar home System	252 kwh
Kerosene for households with electricity access	48 liters
Kerosene for households without electricity access	24 liters
Other electricity uses (household connected to the grid)	130h

3.7 Main factors and Assumptions

For this study population growth and economy are assumed to be the main factors which drive the overall dependency on the forest and hence energy consumption in South West Mau region. Also, urbanization will have influence to some extend as this will create demand for firewood and charcoal.

3.7.5 GDP Economy

"Economic activity was notably subdued in the first quarter of 2019 relative to the performance recorded in the same quarter of 2018. During the period, the economy expanded by 5.6 per cent compared to 6.5 per cent in the corresponding quarter of 2018. The growth, albeit significantly slower than that of the first quarter of 2018, was mostly supported by growths in the service sector industries such as wholesale and retail trade, transportation, accommodation and food services, financial and insurance activities. The quarter was characterized by slowdown in agricultural activities following delay in the onset of long rains. The agriculture, forestry and fishing sector grew by 5.3 per cent compared to a growth of 7.5 per cent in the first quarter of 2018. The slowdown in agricultural growth somewhat affected agro-processing and consequently led to slowed manufacturing activities during the review period." (Knbs, 2019)

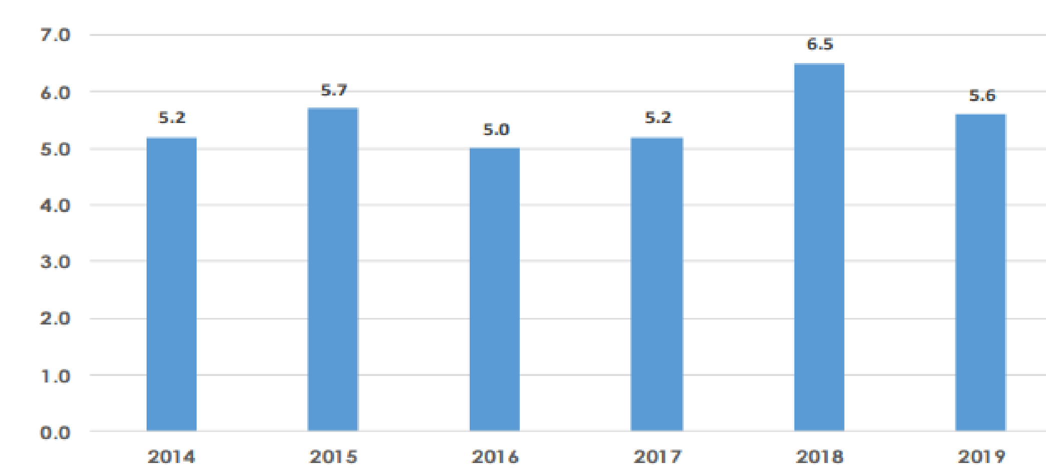


Figure 3-2: The Kenya's yearly GDP growth rate from the year 2014 to 2019. (Source: Kenya National Bureau of Statistics)

The following assumptions were made for this scenario regarding economic growth:

- remain constant to 5.4 % till 2025
- the economy will increase to 6.0 % year-on-year growth on average from 2025 to 2040.

3.1.1 Population

The rate of population increase of Kenya is projected to decrease in the coming decade. This is attributed to increased awareness in family planning as compared to period between the year 1970 to 1980.

Figure 3-3: The rate of population increase in Kenya is projected to decrease in the coming decade (Source: World Bank).

The population growth rate assumed till 2040 is the average growth of 2.5% annually.

3.7.6 Urbanization

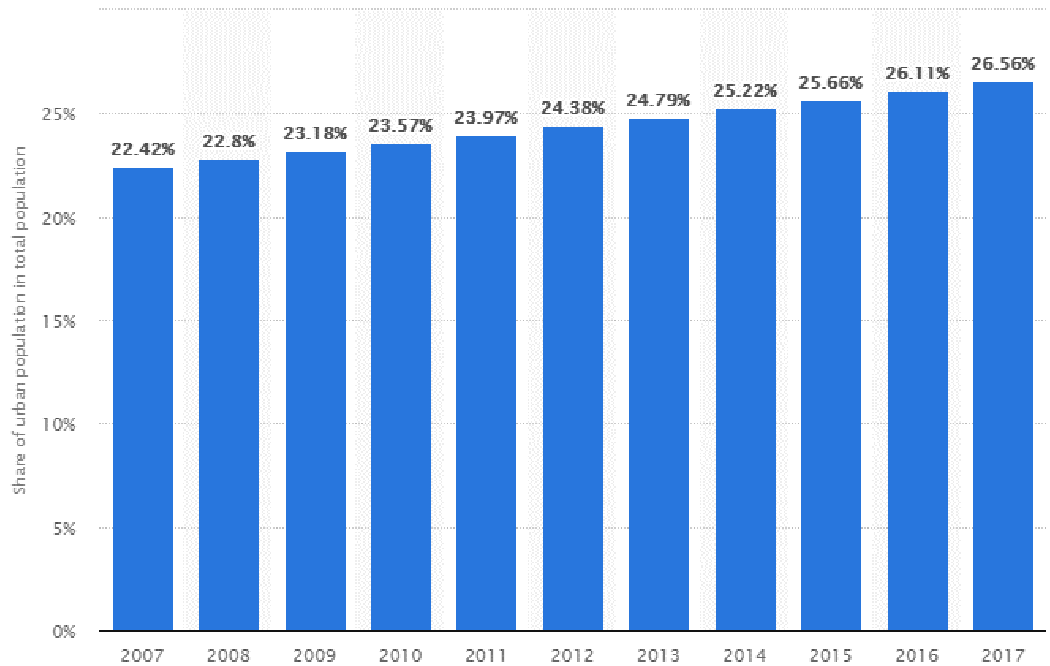


Figure 3-4: Urbanization rate in Kenya from 2007 to 2017. (Source: Statista, 2019)

The share of urban population in total population has been increasing steadily since 2007. As at 2017 the share of urban population stands at 26.56%. From assumption based on the observed trend, 27.5% has been taken as the urbanization rate in Kenya in the year 2019.

3.8 Scenarios descriptions

3.8.1 Business –As- Usual Scenario (BAU)

Basic assumptions and data have been used to inform the Business as usual scenario for the South Western Mau region that will be the baseline against which to measure the scenarios interventions for this study.

The key drivers are summarizing in the Table 3-7:

Table 3-6: Basic assumptions for the business as usual scenario

Key Parameters	*Assumptions in BAU*
GDP growth rate	5.4% till 2040
Population Growth rate	2.5% till 2040
Urbanization growth rate	37.5% by 2040

GDP and Population growth rates considered by on the current prevailing trends as at 2019. Urbanization growth rate was determined by projecting the situation as at the year 2040 by observing the current trend since the year 2007.

3.8.2 Sensitivity scenario Tests

The impact of an Alternatives view of economic growth or population growth in the energy consumption of South Western Mau LEAP model will be explored and analyzed. This will be based on high population growth scenario and also with constant and increased GDP growth scenario.

Population increase

In this scenario called High population growth scenario, there is an increase in population growth by 3 % till 2040.

Constant and increased GDP growth increase

In those scenarios, for the first one called constant GDP growth rate scenario, the growth will remain constant at the rate of 5.4 % till 2025. For comparison with the second one called Higher DGP growth rate scenario where the GDP growth rate increases to 6.5% by 2025 till 2040 will be also considered.

3.8.3 Bio-gas adoption and Clean cookstove Scenario

This scenario model's energy demands up to the year 2040, if policies and strategies to promote modern cookstoves are put in place. Currently, none of the households in the region has adopted the use of biogas while the dominant cooking solution is the traditional three-stone cookstove.

The main assumptions of this scenario are shown in ***Table 3-7***

Table 3-7: Assumptions to model the Bio-digestor and clean cookstoves adoption scenario.

Bio-digestor adoption	20% of the households by the year 2040 80 new bio-digestors in the region annually.
Efficient Charcoal Cookstoves	10% of households by the year 2040
LPG Gas Cookstoves	15% of the households by the year 2040
GDP, Population, and Urbanization growth rates.	Remain the same as in BAU scenario

Due to rural development activities the share of use various clean cooking solutions in both electrified and non-electrified households is expected to change so that by 2040, LPG stoves will be used by 15% of households, and charcoal stoves will be used by 10% (due to population increase.

Biodigester usage will increase to 20% of households. This is due to improvement in campaign on biogas awareness in the region with the aim of having 80 households adopt a biodigester annually. The remaining rural households use wood stoves.

4 RESULTS AND DISCUSSION

4.1 Collection overview

Data have been collected in five different locations. Households interviewed has been sampled so as to cover a larger area within the South west Mau region. In Chebangang village (locality one), 60 households were interviewed. Locality two and three represent Olenguruone village where 28 households were interviewed in total. Londiani (locality four) and Nyangores (locality five), 76 and 52 households respectively were interviewed.

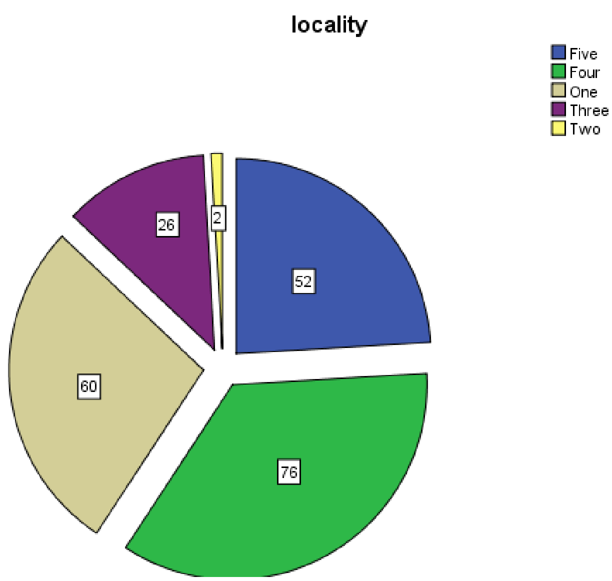


Figure 4-1: Data collection overview in the South West Mau region

4.2 Access to Electricity

In the whole region of South West Mau in general, access to grid electricity is approximately at 17%. This is very low as compared to the national electricity grid access rate which currently stands at 75% (ref). The low electricity access in the region has been supplemented by the use of solar home systems (shs) which currently stands at 36%.

Table 4-1: Primary electricity Source

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	candles	21	9.7	9.7	9.7
	firelight	18	8.3	8.3	18.1
	grid	36	16.7	16.7	34.7
	keroseneLamp	35	16.2	16.2	50.9
	shs	78	36.1	36.1	87.0
	solarLamp	21	9.7	9.7	96.8
	solarTaskLight	1	.5	.5	97.2
	solarTorch	3	1.4	1.4	98.6
	torch	3	1.4	1.4	100.0
	Total	216	100.0	100.0	

4.3 Attributes of Electricity sources

Based on standards to evaluate electricity of the household based on the MTF methodology, it was found out that the capacity of the electricity is meeting the needs of the households according to the appliances owned. The electricity service is also affordable to most of the residents. As shown in Figure 4-2, the electricity source; is always available (reliability), its quality is good and it is safe to use. However, most residents feel that the electricity service provided by the kind of electricity source in their households is not adequate and want change.

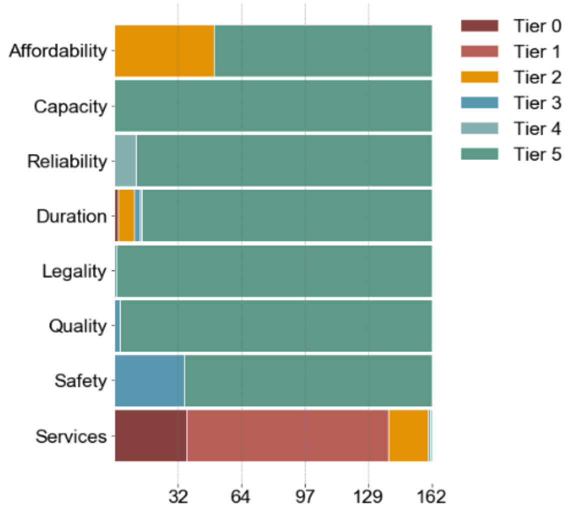


Figure 4-3: Standards (attributes) describing the access to electricity

4.4 MTF Index (Access to electricity)

The MTF Index is given, for each household, by the minimum ranking among all considered attributes. Even though electricity grid access is very low (17%), most residents (48.1%) have been categorized to be in tier five (highest level of electricity access). This is attributed to the adoption of solar home systems which currently provides electricity to 36% of the residents in the region. However, most of the residents (36.4% and 1.2%), as in Figure 4, are still categorized to be in the lower tiers (tier 1 and tier 2). This is attributed to the use of kerosene lamps and candles which do not meet some of the electricity services, like phone charging, required in the household.

Figure 4-4: Multi-tier framework index (MTF) for electricity access.

4.5 Electricity sources

In locality one, Chebangang location, candles and firelights have been observed to be used by most households as a primary source of lighting. These are majorly the low-income households who work in tea plantations. In other regions, a mix of various electricity sources was observed, solar home system being the most adopted electricity source in the region.

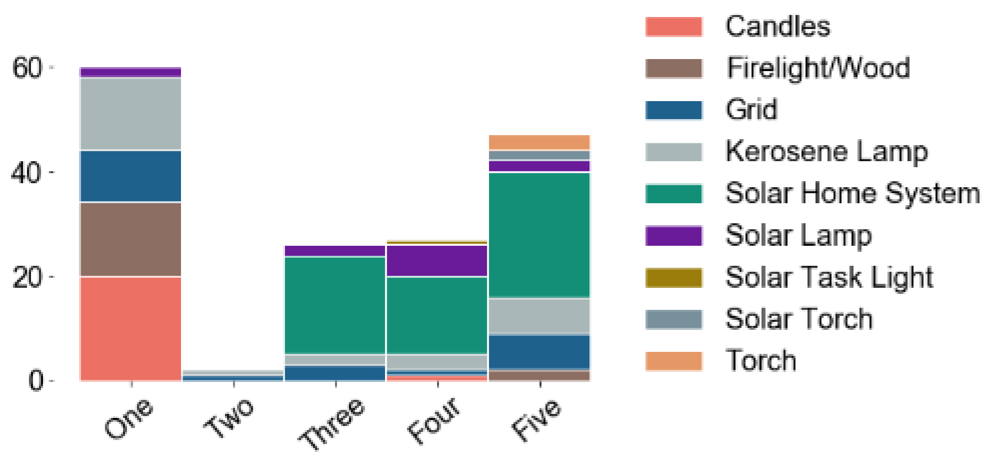


Figure 4-5: Primary electricity Sources in South Western Mau region

In overall, as depicted in Figure 4-6, solar home systems are mainly used as primary source of lighting followed by kerosene lamps and grid. Solar lamp (locally known as "D-light"), candles and firelight are often used as secondary electricity sources.

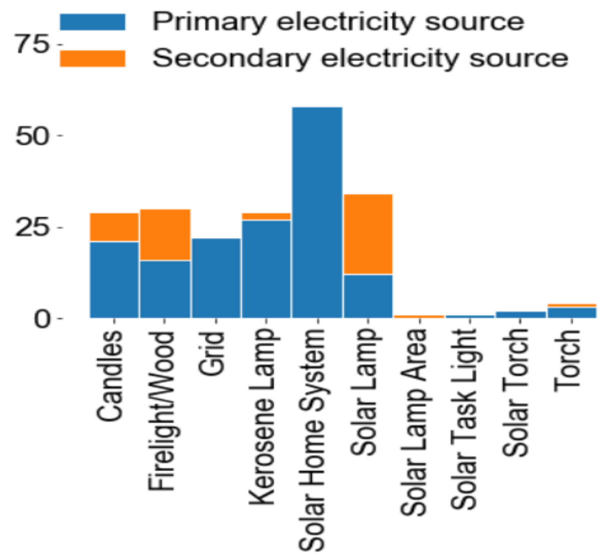


Figure 4-6: Primary electricity source vs Secondary electricity Source

4.6 MTF Electricity Index vs. Primary Source

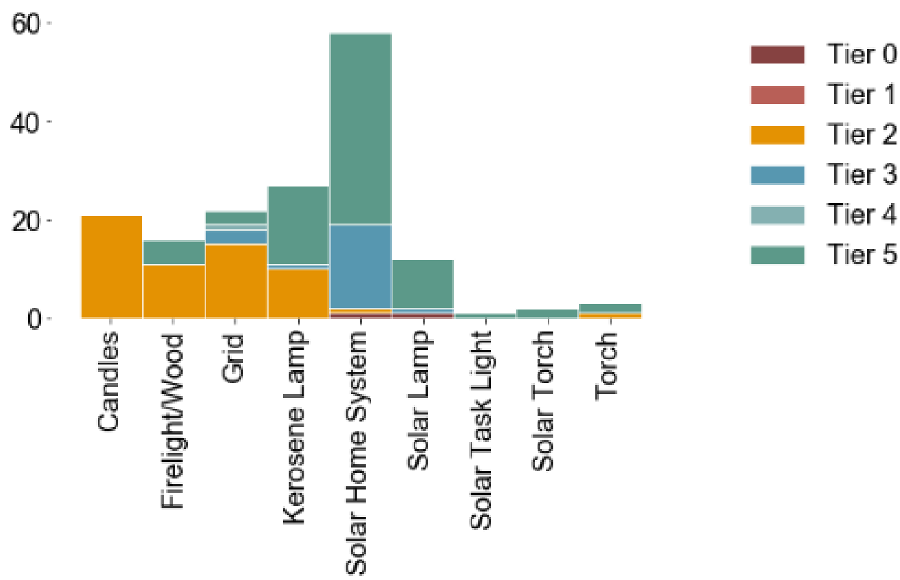


Figure 4-7: Multi-tier framework index of the various primary electricity sources.

On evaluating the primary electricity source based on the multi-tier framework methodology, it was observed that solar home system is meeting the needs of the users as compared to other sources. Over 90% of the users are ranked between tier 3 and tier 5

4.7 Cooking solutions

4.7.1 Primary Cooking fuels

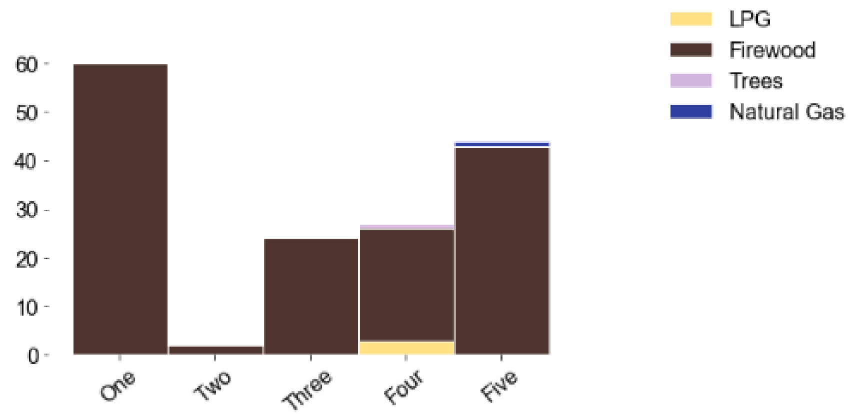


Figure 4-8: Primary cooking fuels in the South West Mau region.

The main cooking fuel in the region is firewood. This is because it can be easily obtained from the forest and it is convenient for use in the homemade stove (3-stone). Liquefied petroleum gas (LPG) was observed to be used by a small fraction of the population in Londiani location, this is attributed to the higher income level of the users.

On average, it was observed that a household consumes approximately 920kg of firewood per year.

4.7.2 Attribute describing access to cooking solutions

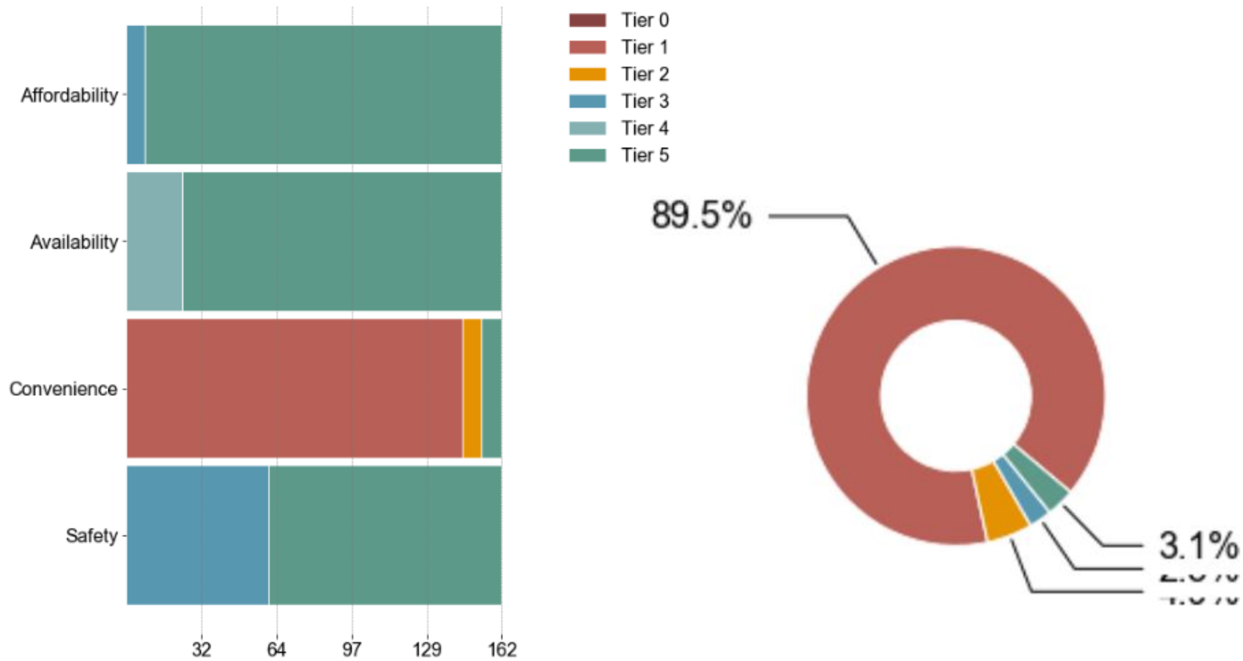


Figure 4-9: Attributes describing access to cooking solutions and the corresponding MTF index.

The MTF Index, for each household, is given by the minimum ranking among all attributes. Though firewood is the main cooking fuel in the region, it was observed to be inconvenient based on time taken in firewood collection and preparation for use. This affects the overall MTF index, thus 89.5% of the users are categorized in tier1.

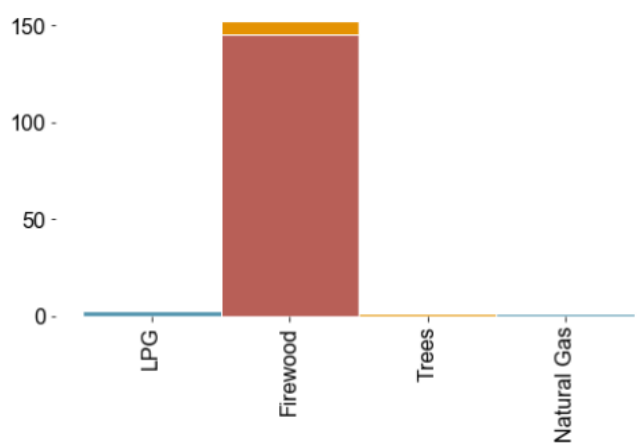


Figure 4-10: MTF index vs. Cooking fuel

As shown in **Figure 4-10**, firewood is the most adopted cooking fuels also the most inconvenient.

4.8 Knowledge about biogas technology

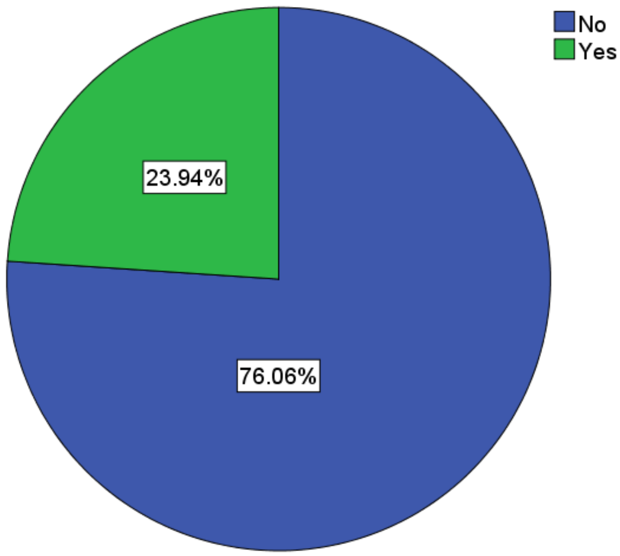


Figure 4-11: Knowledge about biogas technology among the residents of South West Mau forest.

It was observed that most residents do not know about biogas technology, only few have heard about it but not seen it. This is very critical as it determines progress towards achieving SDG7.

4.9 Land size and livestock

Table 4-2: Land size and number of livestock per household.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Number of livestock (cattle) owned by the household	98	1	70	10.91	10.343
Size of land owned by the household in acres	155	1	5	2.40	1.317
Valid N (listwise)	98				

Ownership of livestock is common among residents, on average each household owns ten cattle. Land size is diminishing and there is competition between; cash crops (tea), food crops (maize) and livestock keeping. This has resulted to most households encroaching forest to feed their livestock.

4.10 Relationship between Education, Income and Choice of cooking solution by the household

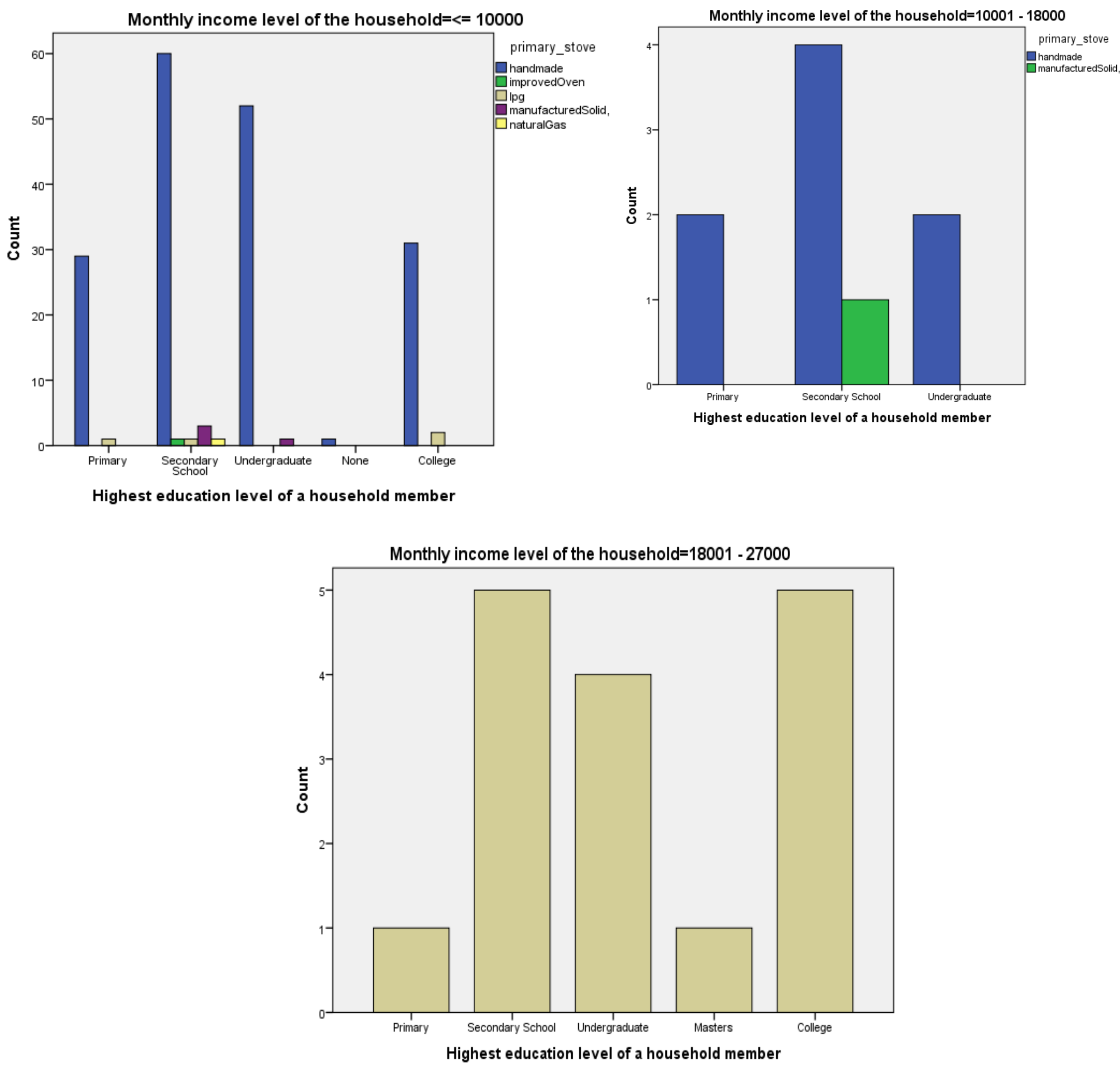


Figure 4-12: Relationship between; highest education level of a household member, income level and choice of cook stove.

Level of Education in the region has no effect on the choice of cooking stove, homemade cook stove is used entirely across the board. However, it was observed that income level could have a little effect on the choice of cook stove by the household. A substantial percentage of households with monthly income level above Ksh. 18, 000 (180 USD) use of liquefied petroleum gas (LPG) as primary source.

The Pearson Chi-square statistic in all categories of income level is higher than 0.05 suggesting that there is no relationship between education level and choice of cook stove

Table 4-3: Cross tabulation results testing relationship between education level and choice of cook stove by considering different income level.

Chi-Square Tests

Monthly income level of the household		Value	df	Asymp. Sig. (2-sided)
<= 10000	Pearson Chi-Square	10.593[b]	16	.834
	Likelihood Ratio	12.551	16	.705
	N of Valid Cases	183		
10001 - 18000	Pearson Chi-Square	.900[c]	2	.638
	Likelihood Ratio	1.275	2	.529
	N of Valid Cases	9		
18001 - 27000	Pearson Chi-Square	.[d]		
	N of Valid Cases	16		
27001 - 35000	Pearson Chi-Square	.[e]		
	N of Valid Cases	2		
35001 - 43500	Pearson Chi-Square	.[d]		
	N of Valid Cases	2		
43500- 51500	Pearson Chi-Square	.[d]		
	N of Valid Cases	3		
51500+	Pearson Chi-Square	.[e]		
	N of Valid Cases	1		
Total	Pearson Chi-Square	11.941[a]	20	.918
	Likelihood Ratio	14.129	20	.824
	N of Valid Cases	216		

a. 26 cells (86.7%) have expected count less than 5. The minimum expected count is .00.

b. 21 cells (84.0%) have expected count less than 5. The minimum expected count is .01.

c. 6 cells (100.0%) have expected count less than 5. The minimum expected count is .22.

d. No statistics are computed because primary_stove is a constant.

e. No statistics are computed because Highest education level of a household member and primary_stove are constants.

4.11 Income Level and choice of cook stove

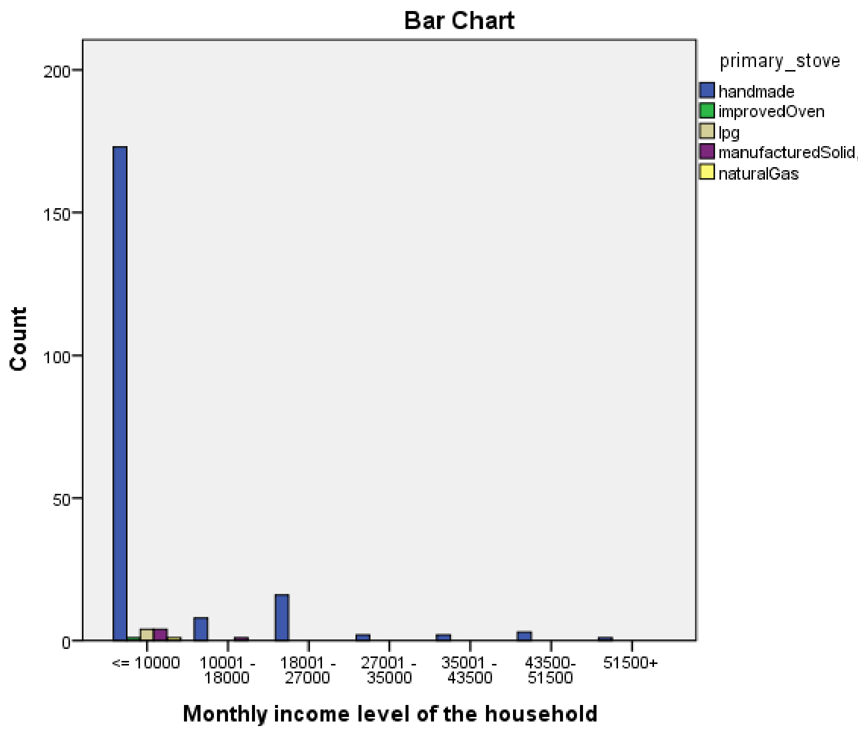


Figure 4-13: Relationship between income level and choice of cook stove.

The use of homemade cook stove (3 stone) is common across all the income level. It is only skewed to the lower income levels since these are the majority of the population in the region.

4.12 Technical and Economic feasibility assessment of bio-digestor

From the statistics of survey carried out, it was approximated that each household in the regions owns 10 cows. For the purpose of adopting livestock intensification strategy, a component of smart dairy farming, each household can comfortably manage two dairy cows.

By applying equation (2), volume of biogas production per household (V_c) was found to be 4, 818 m^3/year. This is equivalent to 428.3 kg savings on firewood per household annually, using equation (4). This further translates to financial benefit of approximately Ksh. 1,600 savings on firewood expenditure annually, calculated using equation (6).

With two dairy cows per household and according to equation (7), 4m^3 digestor is the appropriate digestor size for households in the region.

4.13 Energy Demand by the year 2040 in the South West Mau region

Projections of energy demand in the region based on Business-as-usual Scenario, shows that energy demand will triple by the year 2040 as depicted in Figure 4-14. Demand for cooking fuel will be 16 Gwh (57,600 Gj) as compared to the current demand which is 5.5 Gwh (19,800 Gj). This means that there will be more pressure on the forest if no action is taken. This is because fuel wood will still remain as the primary cooking fuel by the year 2040.

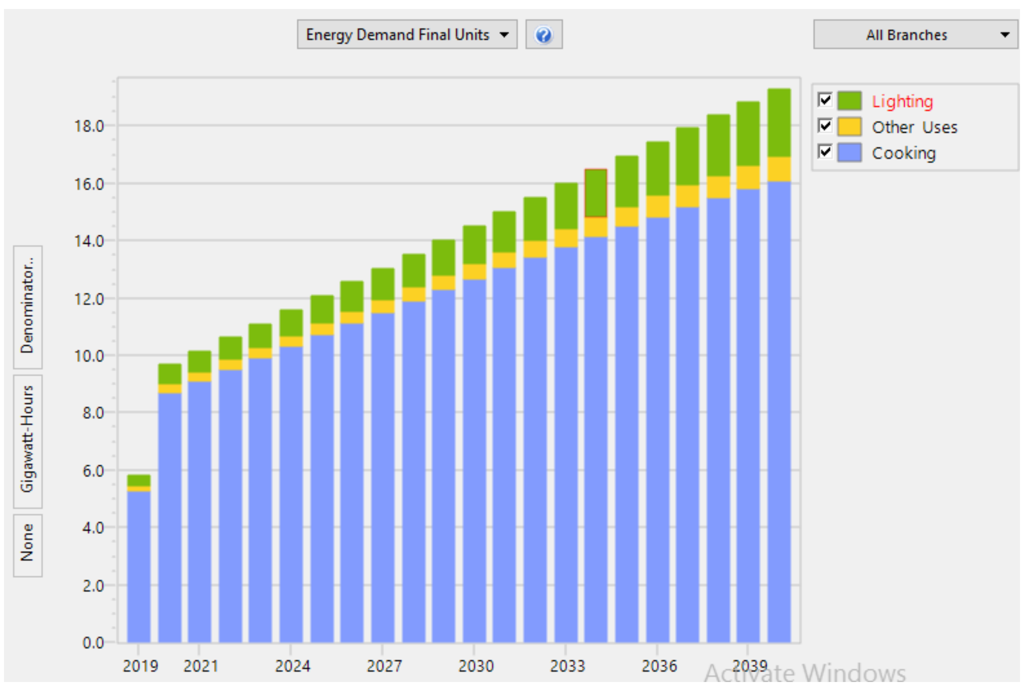


Figure 4-14: Projections of energy demand based on business-as-usual scenario

Due to the current rural electrification campaigns spearheaded by the last mile connectivity project, rural electrification rates will triple by the year 2040. This is according to the conditions of the Business-as-usual scenario.

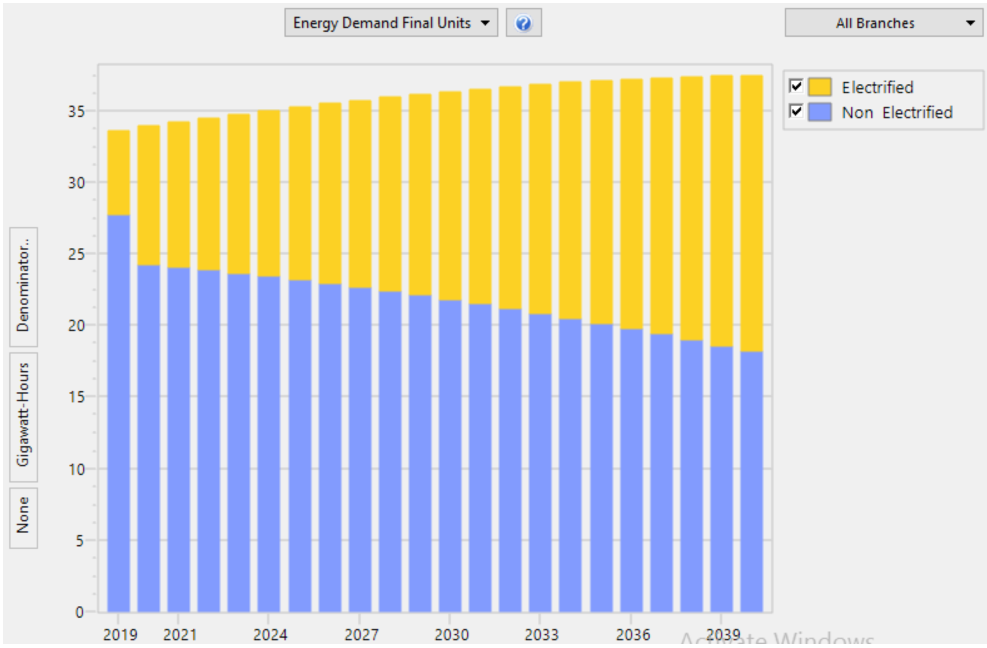


Figure 4-15: Projections of rural electrification rates according to Business-as-usual scenario

4.14 Cooking energy demand by the year 2040 according to Bio-digestor and Clean cookstove adoption scenario

It is observed that by the year 2040, the use of fuelwood will have reduced by half according to this scenario. This is because biogas will account for 20% of the energy demand while both LPG and Charcoal stove contributing 25% of the demand. The results of the scenario is depicted in *Figure 4-16.*

This proves to be a best option in forest restoration efforts as it will tackle the growing pressure on the forest as a result of population increase.

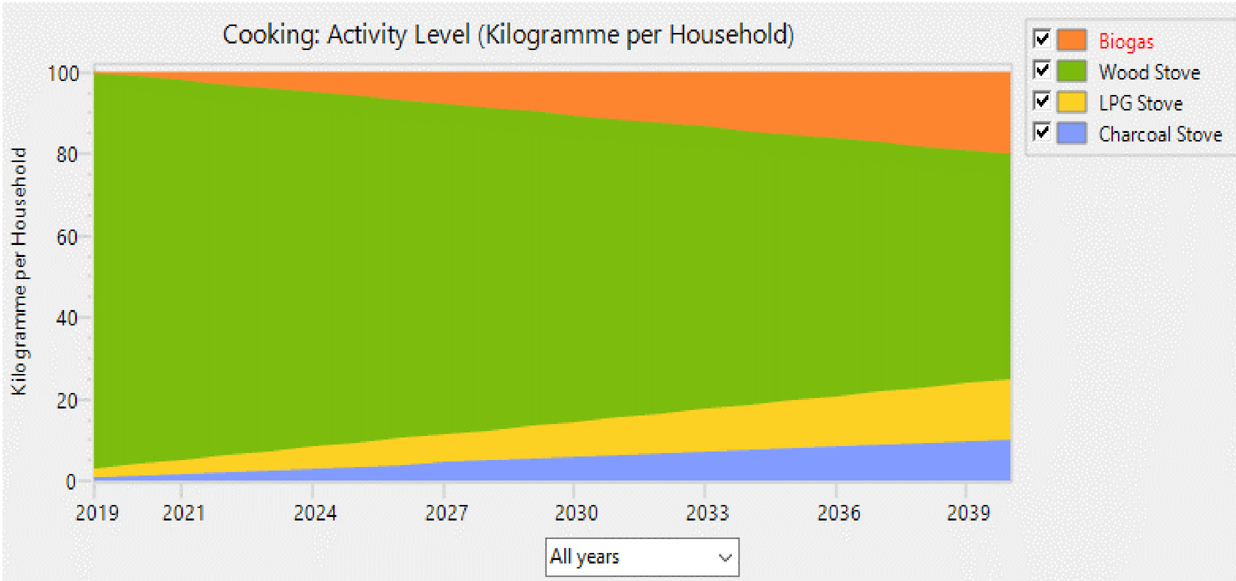


Figure 4-16: The share of energy demand per household according to the Bio-digestor and Clean cookstove adoption Scenario

As population increases, the demand for cooking energy also increases as shown by **Figure** 4-17. It is expected that by the year 2040, with the population growth rate of 2.5%, the number of households in South West Mau region will triple the current number.

By adopting use of biogas technology and clean cooking solutions, the rising demand of firewood use will be constrained.

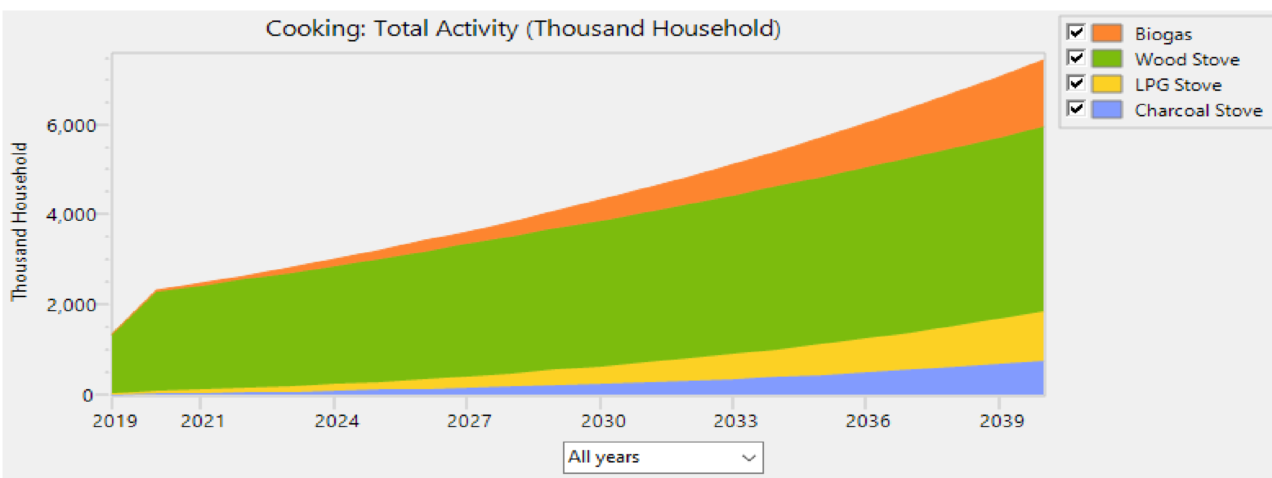


Figure 4-17: Population increase up to the year 2040 in the south west mau region and the trend of clean cooking solutions according to Bio-digestor and Clean cookstoves scenario.

5 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Summary and Conclusion

Data collection was done in four regions; Olenguruone, Chebangang, Londiani and Nyangores. Data was obtained using a questionnaire in 215 households and was supplemented by statistics from reliable secondary sources like Kenya National Bureau of Statistics (KNBS).

Grid electricity access in the region is currently at 17% while the use of solar home systems, currently stands at 36%. Electricity service provided by various sources is affordable, reliable and of good quality but residents feel it is not meeting their daily needs. Also, by analyzing electricity access based multi-tier framework, 48.1% of the residents are categorized in *tier 5* while 37.6% are categorized to be in *tier 1* and *tier 2*. Solar home systems and grid electricity are the main adopted primary sources of electricity in the region while, candle and firelight are used by a fraction of the population as the primary source.

Firewood is the main cooking fuel adopted by the residents in the region. A household uses approximately 920kg of firewood per year. However, a small fraction of population in Londiani location uses LPG as the primary cook stove. This is attributed to their higher income level. By analyzing cooking solutions based on MTF methodology, 89.5% of the residents have been categorized to be in *tier 1*. This is due to inconvenience in time consumed in firewood collection and preparation for use.

Awareness about biogas technology is very low in the region. Only 24% of the residents aware of the technology but have not seen it physically. This has greatly affected it adoption as compared to solar home system which has gained popularity in the region.

Livestock ownership per household is high, 10 cattle, while land size is very small. The available land is shared between food crops (maize) and cash crops (tea), while the remaining small portion is used for cattle shade. Due to limited space, residents resort to forest encroachment in search of livestock feeds.

It was found out that there was no correlation between education level and choice of cooking solution. For residents earning less than 100 USD per month, the Pearson chi-square statistic was 0.834 which is higher than the recommended value 0.05, thus showing that choice of cook stove was independent of education level of a household member.

It was found that bio-gas technology was technically and economically feasible in the region. With two dairy cows, producing 20 kg of dung each, a household is able to produce 4,818 m^3 of biogas annually which is equivalent to 428.3 kg savings on firewood. Financially, a household is able to save Ksh. 1600 on firewood expenditure annually. It was also found out that a typical household in the region can comfortably manage a 4 m^3 bio-digestor.

Considering business as usual scenario, projected cooking energy demand at the year 2040 tripled the current demand. Also, considering the same scenario, firewood will remain the primary cooking fuel and being sourced from the forest. This will put more pressure on the forest resources hence accelerating deforestation.

Rural electrification rates will triple by the year 2040, due to the current rural electrification campaigns spearheaded by the last mile connectivity project.

Number of households in the region is projected to triple by the year 2040 and this will put pressure on the forest due to the rising demand for firewood for cooking. Adoption of biogas technology and efficient cookstoves in the region, will reduce this demand by 50% by the year 2040.

It is evident that by adopting the use of biogas technology and efficient cookstoves in the Mau forest region, will contribute to forest conservation in the long term. This will be due to reduction in the demand for firewood for cooking and elimination of livestock grazing in the forest by adopting improved dairy farming practice. This also indirectly improves household income hence improved standard of living.

5.2 Recommendation

1. Trainings and field days should be introduced in the region to empower residents about modern cook stoves.
2. Non-governmental organizations in the region like Initiative for Sustainable landscapes (ISLA) should incorporate clean energy element in their program.
3. Rural electrification policy by the Rural Electrification Authority (REA) should give equal weight on policies promoting clean cooking solutions as it gives to electrification.

4. County governments through their energy departments should take lead in promoting biogas technology by sponsoring construction of construction of bio digesters in sampled villages for demonstration purpose
5. The livestock intensification program by ISLA in South West Mau forest should incorporate biogas technology to harness livestock waste and produce valuable farm manure

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7 APPENDIX

7.1 Questionnaire

Household Information

1. Please indicate the locality/community/village of the interviewed
2. Click below to save the GPS coordinates
3. Gender of the respondent
4. Enter the identification number (personal ID or client ID) of the person to be interviewed.
5. Please enter identification number again
6. Enter the telephone number of the person to be interviewed (if available)
7. Age
8. Number of people living at the household
9. Total averaged monthly income of the household (in Local Currency)
10. Select Survey modules that will be answered.
    - Additional household information
    - Energy supply and services
    - Cooking solutions
11. Highest Educational level of the family member
12. Marital status
13. Religious affiliation
14. Main source of income
15. Working male adults from household
16. Working female adults from household
17. Total average monthly expenses of the household
18. Total average monthly savings of the household
19. Do you have any livestock?
    - No
    - Yes
20. Cows_ Sheep and Goats__
21. Size of Parcel of Land owned by household

22. Size of the Portion used for livestock keeping
23. Do you know about biogas?

Cooking

1. Take picture of the fireplace
2. Please select all solutions that are used in the home even if they are for occasional use
3. Why do you use more than one stove?
4. Please specify (3-stone)
5. How many times do you cook in a day?
6. Does your fuel source have taste on the food you cook?
7. Are you satisfied with your cooking solutions?
8. Do you have a separate wood burning oven for cooking?

Biogas Stove

1. How important is the biogas stove for preparing meals for home?
2. How much did the household pay for the biogas stove?
3. Was the biogas stove purchased with a loan?
4. How much do you pay monthly for the maintenance of the biogas stove?
5. In what months of the year is biogas available?
6. How long does it take to collect the dung?
7. How many burbers does the stove have?
8. Is the stove in the same space where you sleep?
9. Have accidents occurred due to the use of that stove (or fuel)

Traditional Homemade stove

1. How often do you use the stove made by hand?
2. What fuels are used in the stove manufactured by hand?
3. Is wood the fuel you use regularly to light your stove?
4. Do you collect or buy firewood for cooking?
5. How often do you do it?
6. How much time do you spend each time to buy or collect firewood?
7. How much time do you spend a day preparing the firewood?
8. In what months of the year can this fuel be obtained?

9. Does the quality of the fuel affect cooking?
10. How much do you pay monthly for the maintenance of the stove made by hand?
11. How many burners does the stove have?
12. How long does it take to turn on your stove?
13. Is the stove in the same place where the family or someone sleeps?
14. Is there soot or tissue on the walls where the stove is located?
15. Is it possible to ventilate the stove when preparing the food so that the smoke does not remain in the room?
16. How often do you clean the fireplace in the stove?
17. Have accidents occurred due to the use of that stove (or fuel)
18. Save the current time

7.2 Expenditure

ITEM	DATE		UNIT COST (Ksh)	TOTAL COST IN KSH	TOTAL COST IN DOLLARS
Two way Flight from Algiers to Kenya	26/03/2019 21/08/2019		82,368	82,368	832
Taxi from Tlemcen to Algiers	26/03/2019		4000DA	4000DA	40
Taxi from Algiers to Tlemcen	22/08/2019		4000DA	4000DA	40
Travel Insurance	20/03/2019				50.57
Research Permit					
National govt	30/4/2019		1,000	1,000	
Bomet County	15/5/2019		4,500	4,500	
Kericho County	20/5/2019		4,000	4,000	
Scanning, Photocopy and Printing	17/06/2019	3,000	12,000	12,000	
	31/06/2019	3,000			
	08/07/2019	3,000			
	15/07/2019	1,500			
	25/07/2019	1,500			
Internet Service	03/04/2019	2,000	10,000	10,000	
	04/05/2019	2,000			
	05/06/2019	2,000			
	06/07/2019	2,000			
	07/08/2019	2,000			
Software					
Publication					**(100) To be spend once manuscript is approved by the publisher.**
CHEBANGANG LOCATION					
Data collection. 3 field assistants for five days at Chebangang location, Bomet County	19/06/2019		1000 per day per person	15000	
Data Collection. 1 field guide for five days at Chebangang Location, Bomet County	19/06/2019		500 per day per person	2500	

Data Collection. 7 days of Field Transportation. Chebangang Location, Bomet County	17/06/2019	3000 per day	21000	
LONDIANI LOCATION				
Data collection. 3 field assistants for five days at Londiani location, Kericho County	28/06/2019	1000 per day per person	15000	
Data Collection. 1 field guide for five days at Londiani Location, Kericho County	28/06/2019	500 per day	2500	
Data Collection. 7 days Field Transportation. Londiani Location, Kericho County	26/06/2019	3000 per day	21000	
NYONGORES LOCATION				
Data collection. 2 field assistants for Seven and half days at Nyongores location, Bomet County	02/07/2019	1000 per day per person	15000	
Data Collection. 1 field guide for five days at Nyongores Location, Bomet County	02/07/2019	500 per day	2500	
Data Collection. 8 days of Field Transportation. Nyongores Location, Bomet County	31/06/2019	3000 per day	24000	
OLENGURUONE LOCATION				
Data collection. 2 field assistants for Seven and half days at Olenguruone location, Bomet County	9/07/2019	1000 per day per person	15000	
Data Collection. 1 field guide for five days at Olenguruone Location, Bomet County	9/07/2019	500 per day	2500	
Data Collection. 8 days of Field Transportation. Olenguruone Location, Bomet County	8/07/2019	3000 per day	24000	
TOTAL KSH			**191,500 (exchange rate 1 usd = 98 Ksh)**	**1954**
Final thesis printing	**01/09/2019**		**1500 DA**	**15**
TOTAL in USD				**3031.7**