PAN AFRICAN INSTITUTE OF WATER AND ENERGY SCIENCES (PAUWES)

Tlemcen 13000, Algeria

THESIS FOR MASTER OF SCIENCE IN ENERGY ENGINEERING

Sustainability Assessment of Micro Hydropower Projects: Kenyan Case Study

Author: Lilies Kathumbi

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Supervised By: Prof. Bandari Ramchandra

DECLARATION

Declaration by the Candidate

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ABSTRACT

This thesis assesses the sustainability of community-based micro hydropower projects in remote villages of Kenya. Currently, these projects are very attractive for rural electrification and private industries. The study reviews the Kenyan energy situation and energy indicators commonly used worldwide for assessing projects and systems sustainability. A suitable model for assessing sustainability of the micro hydropower projects was developed in accordance to International Hydropower Association guidelines.

The model was based on five main dimensions: economic, social, environmental, market analysis and technical. From these dimensions, the study developed 23 sub-dimensions and 60 indicators for assessing hydropower sustainability. Data was collected via interviews using open emended questionnaires, group discussions and observation. The sustainability results of community micro hydropower projects were then compared to those of private/industrial hydropower plants as well as that of a solar home system.

The research findings revealed that the Kenyan micro hydropower plants were within sustainable level with an average score of 3.12. Compared to solar PV home system, Micro hydropower was more sustainable. This was attributable to the reliability and affordability of micro hydropower whose Levelized Cost of Electricity (LCOE) was found to be an average of 0.12 USD/kWh. Micro hydropower projects were of great significance to the communities in that they lead to; improved standards of living, improved the community's energy independent, increased study hours for students, and enhanced harmony among the community members. The main challenge that faced this research was lack of documentation for community projects' finances and operations.

ACKNOWLEDGEMENT AND DEDICATION

I offer my gratitude to Prof. Bandari Ramchandra for inspiring and guiding me though my research, and providing insightful comments and feedbacks. Special thanks to Mr. Elly Opiyo and Mr. Geoffrey Makanga who accompanied me to my study sites for my data collection and for their support and feedback. I thank Prof. Brian Rotich and my brother Walter for guiding me in my writing and challenging my report.

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I dedicate this work to my mum Mrs. Kathumbi for her moral support and compassionate inspiration throughout my graduate program.

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ABBREEVIATIONS

CO_2	Carbon Dioxide
EISD	Energy Indicators for Sustainable Development
GDP	Gross Domestic Product
GHG	Green House Gasses
GWh	Gigawatt hour
IAEA	International Atomic Energy Agency
IHA	International Hydropower Association
KENGEN	Kenya Electricity Generating Company
$KgCO_2$	Kilograms of Carbon Dioxide
KSH	Kenyan Shillings
KVA	Kilovolt Amperes
KW	Kilowatt
KWh	Kilowatt hour
LCPD	Least Cost Development Plan
LCOE	Levelized Cost of Electricity
LED	Light Emitting Diode
NGOs	Non-Governmental Organizations
MEPS	Minimum Energy Performance Standards
MHP	Micro Hydropower
MW	Megawatts
O&M	Operation and Maintenance
PV	Photovoltaic
RES	Renewable Energy Systems
R&D	Research and Development

SHP	Small Hydropower
SHS	Solar Home System
tCO_2	Tonnes of Carbon Dioxide
UNDP	United Nation Development Programme
UNIDO	United Nation Industrial Development Organization
USD	US Dollar

CHAPTER ONE

1.0 INTRODUCTION

Renewable energy resources provide affordable and reliable energy to developing countries. Hydropower is one of the most significant sources of renewable and sustainable energy today. For development of hydro power projects, sustainability assessment is relevant through the project's feasibility assessment, implementation up to the operation phase. A conclusive sustainability assessment not only conveys legal and economic gains, but also improves the performance of the project in terms of time and social and environmental integration. Emphasis on sustainability has led to global regulatory changes that make it mandatory for projects to show their sustainability.

Hydropower is among the renewable energy resources that contribute to sustainable development by providing cost effective energy access especially to developing countries. Additionally, hydropower helps to mitigate environmental pollution by reducing emission of Green House Gases (GHG) and harmful air pollutants. Hydropower delivers 91.4% of the world's renewable electricity supply and offsets the need for 4.4 million barrels of oil-equivalent each day (World Commission on Dams, 2000).

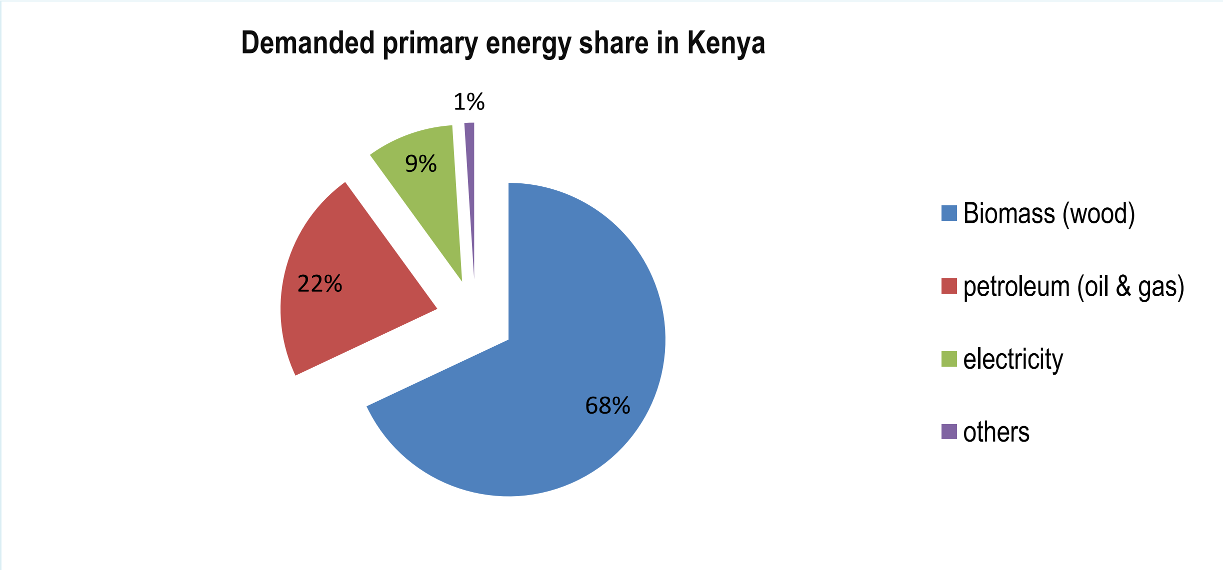
Despite the high potential of the continents water resources, Africa has not fully exploited hydropower. Only 7% of Africa's hydropower potential has been realized which accounts for 80 TWh/y of the estimated potential of 1,143 TWh/y (Taylor & Andrew, n.d).

1.1 Kenyan Energy Status

Approximately 70% of Kenyans have no access to electricity. Most of those people live in rural areas. More than three quarters of the population lives in rural areas and relies on biomass as the major source of energy and agriculture as the main source of income. The national grid has not effectively penetrated the rural areas because they are too far from the grid. Most villages lack access to modern energy services such as lighting. Only 6.7 % of the rural population has access to electricity (World Bank Group, 2016(a)).

Energy is a major driving force in economic development. Most developing countries, including Kenya, rely on renewable energy as a major source of primary energy consumption. Sub-Saharan Africa has abundant renewable energy resources but poor energy supply systems. This makes reliability and affordability a critical factor in the energy sector (International Energy Agency , 2014). According to the Africa energy outlook 2014 report, sub-Saharan Africa accounts for 13% of the world's population and only 4% of the global energy demand. However, there has been rapid economic growth since 2000 and energy use has risen by 45%.

Kenya relies heavily on renewable energy for electricity generation – it is among the most sustainable countries in the world. Renewable energy contributes 80% to the national electricity grid (Kiplagat, Wanga, & Li, 2011). Wood fuel is the capital source of energy in the country; it is mainly used for cooking and heating. The share of renewables in primary energy demanded by the population is high mainly because most people in rural areas depend on wood fuel. Figure 1 below shows energy share from various resources.

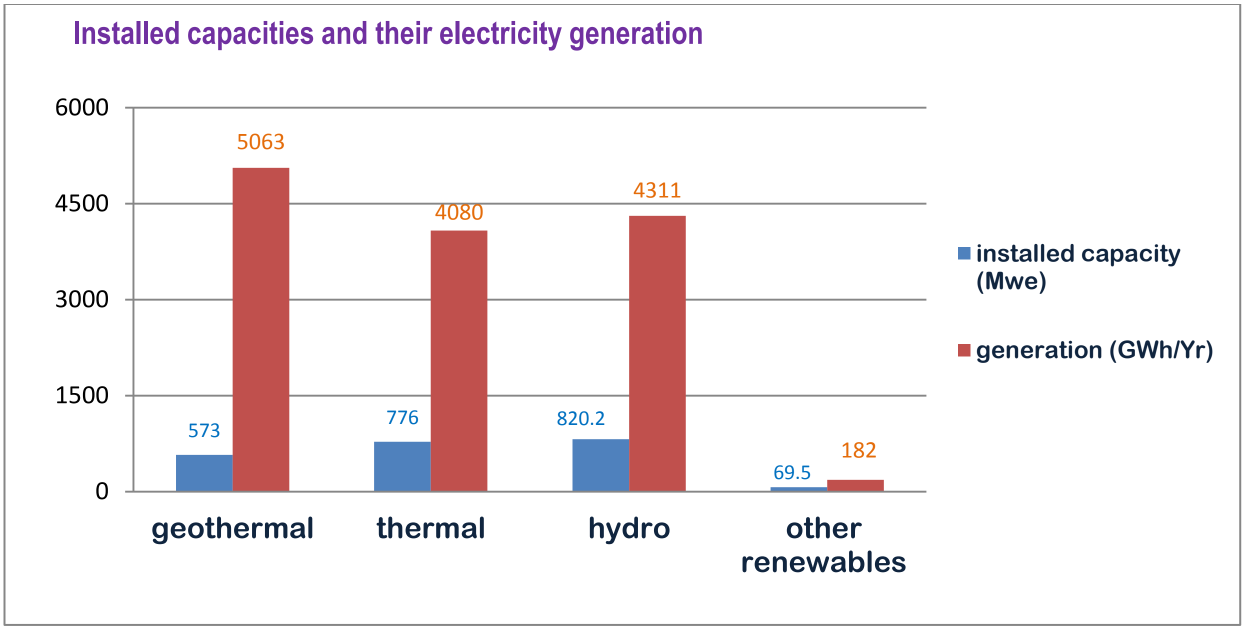


(Omenda, Simiyu, & Muchemi, 2014)

Figure 1: Primary energy share in Kenya

Wood fuel and other biomass products contribute about 68% of demanded primary energy mix, followed by petroleum at 22%, electricity 9% and others such as coal account for 1% (Omenda, Simiyu, & Muchemi, 2014). Petroleum oil is imported and mainly consumed by the transport sector while gas is used for cooking in the cities. Solar energy is traditionally used for drying agricultural products such as fish in rural areas. Omenda et al (2014) noted that coal is mainly used in cement production.

Grid electricity is the primary source of modern energy and energy services in the country. The country had a total installed capacity of 2244.05 MW in 2014, with total generation of 13, 657 GWh/year from a generation mix of hydropower, geothermal, thermal, wind, and cogeneration in sugar industries (Omenda, Simiyu, & Muchemi, 2014). The installed capacity of each technology and the generation is shown by the figure 2 below.



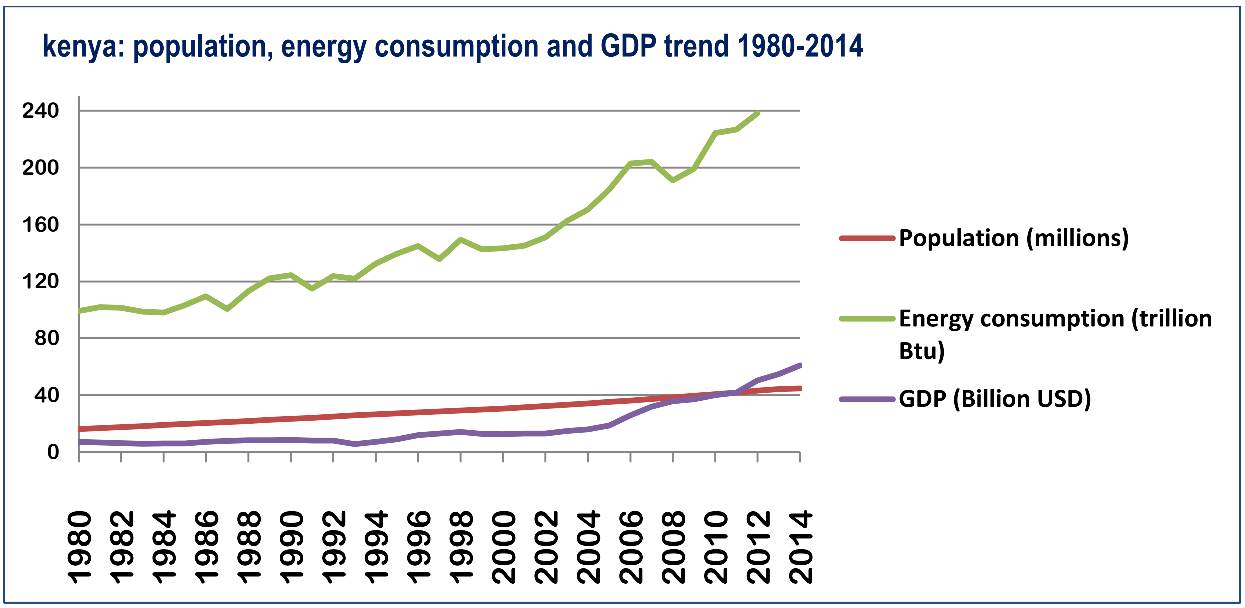
(Omenda, Simiyu, & Muchemi, 2014)

Figure 2: Installed capacities and their electricity generation

Hydropower has the highest installed capacity in the country but its electricity generation is low due to climate change that affects river capacities. Geothermal is the leading source of electricity generation due to the development and maturity of technology in the country. Thermal electricity is the third source of electricity in the country. The thermal plant is heavily dependent on oil imports. Imported oil is used in industrial processes and stand by generators especially over the dry seasons when hydropower supply is low and power black outs are common

Other renewables include wind energy, cogeneration and solar energy. Solar Photovoltaic (PV) is common for home lighting and charging appliances like mobile phones especially in not connected to the grid. Cogeneration is common in sugar industries for both heat and electricity, as is the case in the Mumias Sugar Company (Omenda, Simiyu, & Muchemi, 2014).

More than half of the Kenyan population lives below the poverty line and is unable to meet its daily needs, including energy services. There exists a linkage between energy and economic and economic growth (UNDP, 2004). According to the UNDP report, the economic growth can be measured in terms of; social status, health issues, women standards of living, poverty eradication, environmental protection and security. Increase in energy consumption is an indication of growth in the economy of a country, which leads to improved living standards. Figure 3 below shows the relationship between population growth, energy consumption and GDP growth in Kenya from 1980 to 2014.



(U.S Energy Information administration, 2014)

Figure 3: Kenyan; population, energy consumption and GDP trend

Data on population, energy consumption and CO_2 emission was obtained from the U.S Energy Informationl administration (2014).

Both energy consumption and Gross Domestic Product (GDP) have had rapid growth from 2000 to 2007 when there was a political crisis that disrupted the economy and energy supply of the country. The GDP grew to 6.1% in 2006, new economic development program towards Kenta vision 2030 aims to accelerate GDP growth by 10% per annum for the next 25 years (G.O.K, 2007). It is evident that economic growth increases with increase in energy consumption, thus explaining the linkage between the two aspects. However, for most developing countries energy consumption does not necessarily indicate economic growth since most of the energy is in traditional biomass form (African Development Bank, 2015).

Development in the energy sector in Kenya is mainly geared towards sustainability. Sustainability is the ability to meet current demands without compromising the ability of future generations to meet their own demands.

Sustainable electricity generation not only boosts social and economic development but also environmental and global climate change management. For these reasons, sustainably is very important to the achievement of millennium development goals. Generation of electricity from renewable energy resources such as hydropower is currently the best practice for minimizing the effects of current environmental degradation and climate change (Kaunda, Cuthbert, & Torbjorn, 2012).

1.1.1 Renewable resources potential

Kenya has abundant renewable energy resources: solar, geothermal, hydro energy, wind energy, and biomass.

a) Wind energy

The country has a potential to produce and add over 1000 MW of wind power to the national grid but the installed capacity is only 5.1 MW. The wind speeds in areas of high potential such as Ng’ong, Turkana, Marsabit, Laisamis and Samburu range from 8 m/s to 14 m/s (Energy Regulatory Commission, 2012). Challenges facing the wind sector include lack of reliable data on wind potential and the high investment costs of the technology. Areas with high potential are also located far from the national grid and are sparsely populated.

b) Solar energy

Solar potential in Kenya is huge with most of the country receiving a daily insolation of 4-6 kWh/m^2 (Energy Regulatory Commission, 2012). Most of this energy is used as solar drying, water heating, and solar Photovoltaic (PV) for telecommunication, cathodic protection of pipelines, lighting and water pumping (Republic of Kenya, 2011).

c) Hydropower

The country has high hydropower potential, current hydropower installed capacity is 820.2 MW (Omenda, Simiyu, & Muchemi, 2014). The small hydropower installed capacity is 30 MW (with only 15 MW supplied to the grid). Small hydropower is unexploited with its potential estimated at 3000 MW. The main challenge facing large hydropower plants in Kenya is climate change especially in dry seasons when there is low water lever in rivers. This has greatly affected power generation leading to power rationing and over dependence on thermal plants over the dry seasons.

d) Biomass

Biomass is the single most commonly utilized primary source of energy in Kenya. Solid biomass attributes to 70% of final countries energy demand and accounts for about 90% of rural energy needs (Energy Regulatory Commission, 2012). Biomass in is mainly used as wood fuel for cooking and heating in traditional form in rural areas. Besides the national wide campaigns on use of improved cooking stoves to save wood fuel, the uptake has been slow due to capacity constraints (Republic of Kenya, 2011).

e) Geothermal energy

Geothermal is the fastest growing electricity generation technology in Kenya in the last decade. The countries potential is estimated to be 7,000 to 10,000 MW within the Rift-valley province. The total installed capacity by 2014 was 573 MW (Omenda, Simiyu, & Muchemi, 2014).

Renewable energy technologies provide the most suitable and sustainable means for small grids and off-grid region where grid connection does not exist due to geographic limitations. In many developing counties including Kenya, these micro grids have been effective for community based electricity access, institutions and private companies' power generation such as tea processing companies.

There is great potential to harness the renewable energy and improve energy access in the country by investing in current technologies and R&D. The country's renewable energy resources are still under exploited only; 30% of hydropower, 4% geothermal and small proportions of wind and solar energy has been harnessed (Kiplagat, Wanga, & Li, 2011)

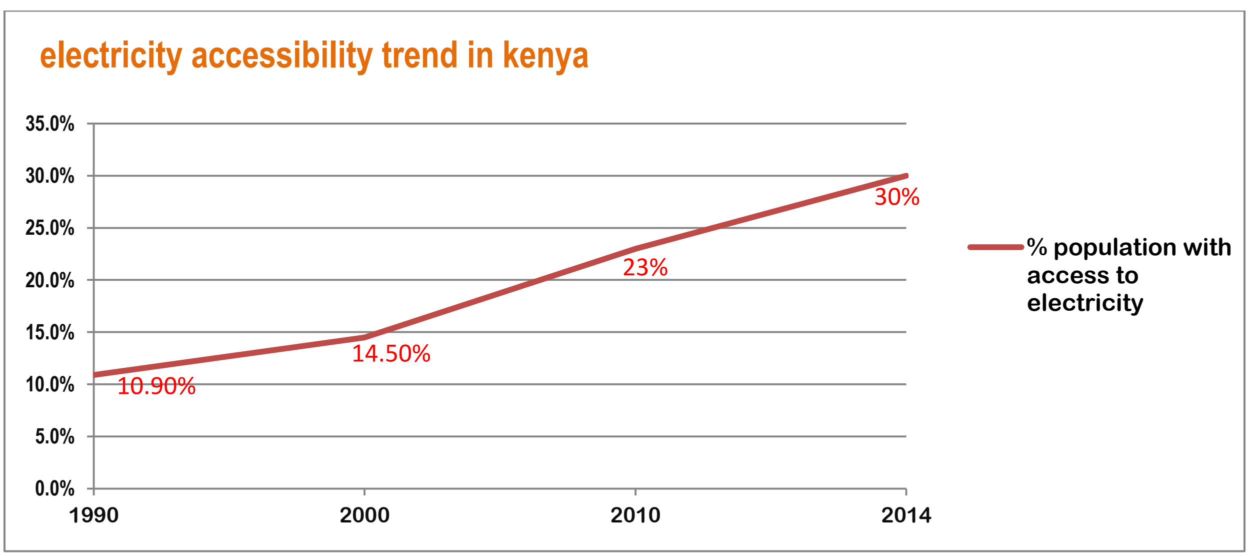
1.1.2 Electrification in Kenya

The number of people without access to electricity in developing countries is increasing due to lack of sufficient energy for the growing population despite the enhancement of rural electrification programs. 80% of the world's population in developing countries lives in rural areas and consume only 20% of the global commercial energy (European Small Hydropower Assocciation, 2006).

For economic development, Sub-Saharan Africa countries have to invest in energy sector for affordable and reliable modern energy services. Most of these countries: 30 out of 48 are prone to daily power outages which cost between 1% - 5% GDP in Kenya, Tanzania and Senegal whereas in Uganda it is more than 5% (International Renewable Energy Agency, 2011).

Kenya has experienced rapid economic development since 2007. This has been mainly attributed to the national development plan, **Kenya Vision 2030** and facilitated by Energy Act of 2006 that created Rural Electrification Authority (REA). REA is an independent body formed to stimulate electrification of rural areas in the country through extensions, stand-alone systems and isolated mini-grids. The agency is to accelerate the electrification by renewable energies only so as to promote sustainability.

In areas where diesel generator plants exist, hybrid generation with renewable energy was to be implemented. By 2013, REA had 90% of public facilities electrified; these include secondary schools, markets and health centers. By year 2014, 30% of Kenyans households had access to electricity (Economic Consulting Associates, 2014). The trend of electrification rates is shown by the figure 4 below;



(Economic Consulting Associates, 2014)

Figure 4: Electrification rates and trend in Kenya

From figure 4 above, there has been rapid increase in electricity accessibility since 2006, when rural electrification was emphasized by governmental policies. This was made possible by extending the national grid to rural areas. The country is currently on its path to industrialization and increase in electricity demand is an indicator of developing progress. Private investors as well as Non-Governmental institutions have also set up mini-grid to supply electricity to isolated remote areas, for example Tungu-Kabiri and Somorio micro hydro projects.

Electrification rates in Kenya are still low since majority of the population still lack access. Electricity is currently expensive for the poor majority; the cost per kWh being approximately 0.2 USD. Most communities even though connected to the grid majority of the habitants cannot afford for its installation and monthly consumption bill hence live without modern energy services. Community based energy projects are thus the cheaper way for energy access to such remote communities. Organizations such as United Nation Industrial Development Organization (UNIDO) have set up many community hydropower projects like Tungu-Kabiri and Somorio. These projects were among the plants visited during the study; these projects are of great help to the poor communities.

Kenyan economic development policies are focused to the countries development plan; Kenya Vision 2030. It’s a social, economic and political plan which covers the period 2008 to 2030. The plan highly reorganizes development in the energy sector as the main driving factor towards economic development. The National plan targets 65% electrification by the year 2020 and 100% by the year 2030 (Republic of Kenya, 2011).

The main challenges facing the country in exploitation of natural resources for energy generation are mainly; lack of financing, poor participation of private sector and lack of data on energy pricing as well as market awareness.

The main policies in place for; affordable, reliable, cost effective energy services and accessibility towards the Vision 2030 are:

i. Energy Act 2006: through this Act, REA was implemented to accelerate electricity accessibility in the country,

ii. Feed in Tariff policy 2008: enacted to mainly attract investment in; small hydro, solar, wind and biomass energy development. It has special rates ranging from USD 0.06/kWh to USD 0.12/kWh.

iii. Least Cost Development Plan (LCDP): focuses on; Load forecast, generation planning and transmission planning to meet an electric power supply target of 3000 MW by 2018.

The main market structure and institution framework in place to enact policies on modern energy access through renewable resource exploitation in Kenya are as discussed below (Republic of Kenya, 2011);

- Ministry of Energy (MoE); mandated by both the policy and law for overall coordination of energy sector. It is responsible for formulating and articulation of policies to provide enabling environment for all operators and stakeholders in the energy sector.
- Energy Regulatory Commission (ERC); serves as the sole regulatory body for the Kenyan energy sector.

- Kenya Electricity Generating Company (KenGen); the public utility responsible for electricity generation.
- Kenya Electricity Transmission Company (KETRACO); responsible electricity transmission.
- Kenya Power and Lighting Company (KPLC); public utility responsible for electricity distribution.
- Geothermal Development Company (GDC): it is the central authority dealing in geothermal power development. The central responsibility is exploration of drilling to realize steam fields.
- IPPs: they are becoming significant players in the electricity sector following new energy policy.
- Kenya Renewable Energy Association (KEREA) is also a body that is influencing uptake of renewable energy especially solar energy for off-grid use in Arid and Semi-Arid Areas (ASAL).

Policy makers, Non-Governmental Organizations (NGOs) and private developers can play a major role in increasing accessibility of modern energy in rural areas. It is mostly assumed that the areas are too far from the national grid and expensive to extend the grid to rempte areas. However, mini-grids and stand alone off-grid energy system would be the best solution to supply modern energy to 70% of rural dwellers in developing countries (Kenneth Lee, et al., 2015).

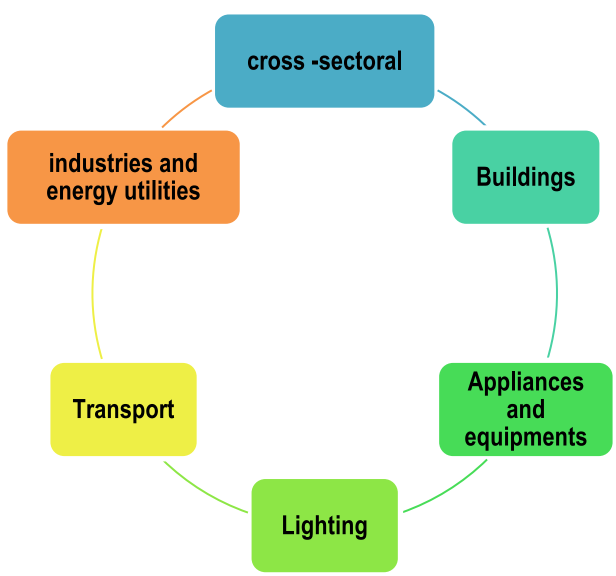
1.1.3 Recommendations for sustainability in energy use sectors

Energy sector is essential for the development of the Sub-Saharan Africa. In order to ensure energy sustainability in Kenya, there is need to work on energy efficiency so as to ensure optimal use of energy resources. Energy efficiency curbs growth of energy demand, mitigates pollution and reduces oil imports. According to New Policies Scenario, energy efficiency account for 70% reduction in global energy demand projection for 2035 and saves 68% of cumulative CO_2 emissions (IEA, 2012).

According to World energy outlook 2012 report, attaining energy efficiency will be a least cost way of addressing challenges in the energy sector such as; energy security, economic, and environmental concerns.

Assessment of sustainability and continuous monitoring of performance in various sectors in a country is recommended to improve overall sustainability of energy systems and energy use.

The priority areas that require consideration to ensure sustainability in developing countries are shown in figure 5 below as an all-round phenomenon.



(IEA, 2012)

Figure 5: Sectors of priority for sustainability

Several recommendations have been set as guidelines on the above priority areas. They include policies that would increase energy efficiency in a cost-effective way through establishment of market signals for action, increase the rate of introduction of new technology, enforce use of appliances, lighting, and building codes that adhere to the Minimum Energy Performance Standards (MEPS).

Globally, implementation of the recommendations would result in saving as much as 7.6 gigatones of CO_2/year by 2030 a figure that is about 1.5 times the value of CO_2 emission from the US. According to efficient world scenario, energy demanded will reduce by 2,350 Mtoe in 2035 of which 85% is a result of efficient energy measures by the end user (IEA, 2012).

i. Cross-sectoral

Sustainability cuts across all sectors since they are all linked in development, one sector cannot develop at the expense of other sectors. The recommended for cross-sector efficiency check include;

a) Energy efficiency data collection and indicators to aid in development and assessment of energy efficiency strategies and policies,
b) Strategies and action plans based on analysis of energy use, markets, technologies, and efficiency opportunities. There is need for the government to perform regular updates of the strategies and action plans to ensure improvement in energy efficiency throughout the domestic economy.

Best practice strategies and action plans should:

- Identify and minimize or overcome barriers to cost-effective efficiency investment.

- Assess opportunities and prioritize in sectors or/and end use areas with the largest cost-effective improvements.
- Have clear objectives and timelines and have evaluation
- Ensure coherence with economic strategies and plans as well as energy, and environment/climate.
- Consider events taking place in other countries.

NB: there should be continuous coordination and integration of new and emerging technologies.

c) Competitive energy markets that are guided by periodically reviewed regulations and subsidies. It will ensure retail energy prices take into account full costs of energy supply and delivery (including environmental costs).

d) Private investment in energy efficiency. The government should facilitate through capacity building, standardizing measurement and verification protocols, and research. It can be achieved via:

- Knowledge generation and dissemination through networks or energy advisory service.
- Education and training programs across all sectors on energy efficiency.
- Develop measures and verification protocols for consistency, overcoming uncertainties, and stimulate more participation by the private sector.
- Public-private partnerships

e) Monitoring, enforcement, and evaluation of policies and measures. Done through using results of a program or policy to inform decision. Baseline assessment and periodic review and reporting. A transparent process should identify non-compliance and an associated penalty applied.

ii. Buildings

In order to ensure energy efficiency in buildings;

- There should be mandatory building energy codes that meet MEPS.
- The aim should be net-zero energy consumption with specified targets included in policy formulation
- Improve energy efficiency of existing buildings especially during renovation. Measures included energy audits, rating and certification schemes
- Introduce energy labels or certificates to notify owners, buyers and renters.
- Establish policies that will ensure overall improvement of energy performance of all buildings especially on critical components such as HVAC (heating, ventilating and cooling) systems.

iii. Appliances and Equipment

Appliances in homes and offices consume more energy especially if they are not used effectively for the right purposes or wrongly rated appliances are used. The recommendations advocated for mandatory labeling of appliances and equipment and allocation of resources to monitor compliance. There should be regular update of test standards and measurement protocols to determine their usage and energy consumption. To attract more investors the government is urged to use incentives to transform market policies on new technologies. Old appliances consume more energy, replacing with newer ones that consume less would be cheaper at long run.

iv. Lighting

Most modern energy services in rural areas are mainly used for lighting. Lighting consumes most energy in institutions and offices. Proper building design to utilized natural lighting is highly recommended to save on energy.

The recommendations are to;

- Phase-out inefficient lighting products and systems
- Require and promote use of improved lighting systems
- New building codes to factor in use of natural light

v. Transport

Kenyan transport sector is highly dependent on imported fossil fuel which is a challenge to the national economy. Introducing energy efficiency measures to conserve energy in this sector is a great challenge. These measures can be achieved through;

- Mandatory vehicle fuel efficiency standards that are periodically strengthened
- Develop policies to improve performance of; air conditioning, lighting, and other components that affect efficiency,
- Strengthen incentives that encourage buying of efficient vehicles,
- Improving driving school curriculum to include eco-driving ,
- Improve efficiency in the transport system especially in urban areas,

vi. Industry and energy utilities

All industry should undertake energy management strategies and implementations for energy sustainability. Policies in Kenya require conformity to ISO 50001 standards on energy management which emphasis on energy efficiency and energy audits. Industries can optimize on energy use through using high-efficiency industrial equipment and systems.

With regards to small and medium enterprises, the government should develop policies that ensure promotion of energy efficiency. There should be high-quality and relevant information to allow for international and local comparison. In addition, there is need to put in place complementary financial policies that will promote investment in energy-efficiency in industries.

The government can strengthen energy utilities through policies and regulations that ensure they remain supportive on cost-effective, end-use energy efficiency. For instance, the government can utilize energy tariffs as a funding mechanism for energy efficiency. Developing countries are focusing more on exploiting renewable energy resources which are sustainable and contribute greatly to economic development. However, development of renewable technology is highly hindered by financing leaving majority of the population relying on biomass as the major source of energy.

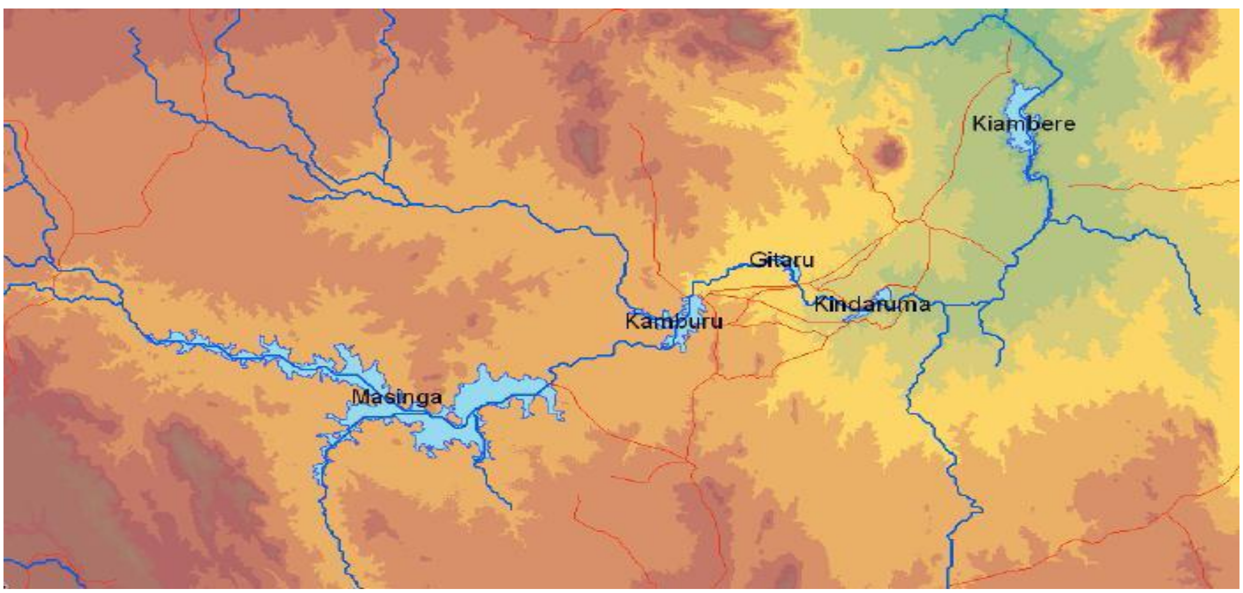
1.2 Hydropower Technology

Hydropower is currently the most mature, reliable and cost effective renewable energy technology. Hydropower is amongst the technologies that provide the lowest cost of electricity generation. The Levelized Cost of Electricity (LCOE) of large hydropower plants at best site being as low as USD 0.02/kWh while that of small hydropower projects has an average of USD 0.05/kWh (IRENA , 2015(b)). Hydropower is most attractive power generation technique due to its ability to meet fluctuating load demand, its ease to start or shut down, low GHG emission and long life span.

In a hydropower plants, the kinetic energy in water current is converted to mechanical energy by a turbine. The turbine is coupled to a generator which in turn converts the mechanical energy to electrical energy. It is a very old technology that was used in the early stages for milling and gridding grains by water mills.

While hydropower technology offers significant economic and social advantages, its sustainability has stirred criticism especially when analyzed on environmental aspect. However this depends on policy and regulations of a given country. Large hydropower development is still attractive worldwide. In Africa large hydropower development is evident by the ongoing construction of the Grand Ethiopian Renaissance dam (6,000 MW) and the proposed Grand Inga Dam of Congo (39,000 MW). These large hydropower projects are economical for regional energy access and infrastructure development as well as regional cooperation in Africa.

Most of the large hydropower plants in Kenya are located in central region along river Tana while small and micro are in mountainous locations such as Mt. Kenya and Kericho. Figure 6 below show main hydropower plants and their locations:



(Source: Droogers, *et al.*, 2006)

Figure 6: Large hydropower plant sites in Kenya

As shown on the map in figure 6, large hydropower plants in Kenya are concentrated along river (Tana) and form cascades known as the Seven Forks. All these large hydropower plants supply electricity to the national grid. Overdependence on the same river makes reliability of electricity vulnerable especially during the dry seasons that greatly affect river Tana.

In areas where the resource is abundant, large hydro technology provides additional services to electricity generation such as: irrigation, flood control, water distribution, navigation, recreation and water storage.

Global wide, many countries (about 160 countries) rely mainly on hydropower for electricity generation. In 2011 hydropower global share of installed capacity was 19.4% accounting for 15.8% of global electricity generation (IRENA, 2015).

Kenya hydropower generation is a mature technology in having both large and small-scale hydropower. The first large hydropower was developed 1968 with an installed capacity of 72 MW. Up to the year 2013 hydropower was the main electricity generating technology with total installed capacity of 745 MW. Subsequently generation by hydropower has declined over years due to water level variations in dry seasons.

1.2.1 Classification of hydropower plants

Hydropower plants are generally defined as large hydropower or Small Hydropower (SHP) depending on their installed capacities. However, they can be further classified in several ways depending on their; mode of operation, capacities, head, turbine characteristics, load characteristics and interconnection as discussed below;

a) Mode of operation

- Run off river plants; are made by diverting water from a river course, they may be with or without pondage. They are highly susceptible to variations in river changes.
- Impoundment plants; have a dam constructed across a river forming a reservoir for water storage. They are mainly large hydropower plants.
- Pumped hydropower plants; water from reservoir is utilized for electricity demand during peak demand, during off peak the water is pumped back to the reservoir using the excess power.

b) According to head

- Low head plants: up to 10M
- Medium head plants: between 10-100M
- High head plants: above 100M

c) According to turbine characteristics

- Low specific speed: 10-60
- Medium specific speed: 60-300
- High specific speed: 300-1000

a) According to load characteristics

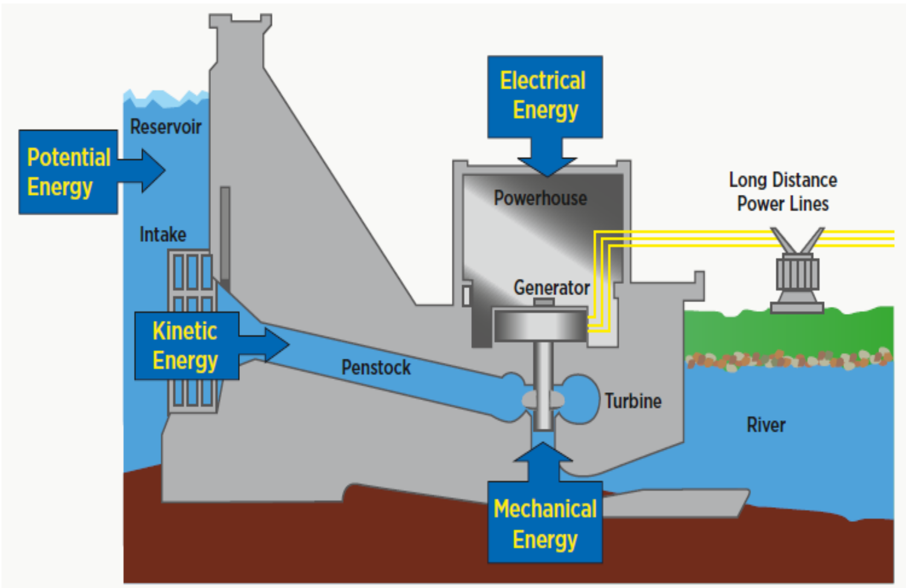
- Base load plant; operates continuously and generates power throughout the year
- Peak load plant; only generates power during peak hours

b) According to interconnection

- Isolated plant; power station operates independently, either an isolated grid for a community or industrial purpose.
- Interconnected plant; the power station is connected to the national grid.

1.2.2 Components of hydropower plant and its operation

The main components of hydropower plants are as shown in figure 7 below:



(Alternative Energy, 2006)

Figure 7: Components of hydropower plant

The dam is an impounding structure that creates a reservoir behind it for water storage. It creates a head and ensures continuous water flow for steady power supply. A penstock is a water conduct system from the fore intake in the dam to the turbine nozzles. The turbine is the wheel that transforms kinetic energy of water to mechanical energy; it is connected to a generator for electricity generation. Both, the turbine and the generator are housed in the powerhouse. Generated electricity is then transmitted for distribution by the transmission lines. The outflow (tailrace) allows water to flow back to the river course.

The power generated is directly related to the available head and the water flow rate. However, not all energy in the water is converted to electricity; this is due to mechanical losses of the turbine and the generator. The hydraulic power generated is computed as below (equation 1):

$$\boldsymbol{P} = \boldsymbol{\rho} * g * \boldsymbol{Q} * \boldsymbol{H} * \boldsymbol{\eta} \qquad \textbf{(Equation 1)}$$

Where:

P = Hydraulic power (kW)

ρ = water density (Kg/m^3)

g = acceleration due to gravity (9.81 $m/s^{2)}$

Q = flow rate ($m^3/s^{)}$

H = effective head (m)

η = overall efficiency of the hydropower plant (for estimation it is taken as 0.85)

Electrical energy generated by a hydropower plant can be computed from the power generated as shown by equation 2 below:

$$\boldsymbol{E = P * \Delta T} \qquad \textbf{(Equation 2)}$$

Where;

E = energy generated (kWh)

P = hydraulic power (W)

ΔT= time period (hours)

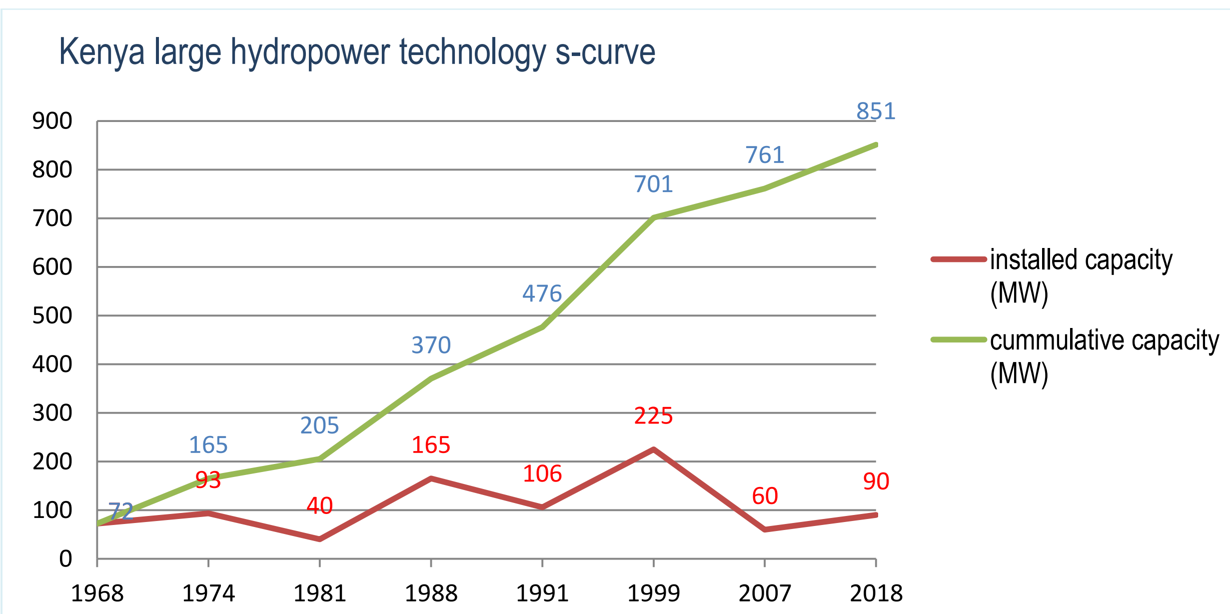
Hydropower has many advantages; first it is a stock resource and a cost effective technology, water is always available and after running the turbines it is utilized downstream. Secondly it is a mature technology that is easy to learn and its running cost is very low in comparison to nuclear and thermal plants. The technology has advanced high efficiency generators that have boosted the efficiency of the system.

On the other hand, hydropower has several setbacks. The technology requires high capital investment and the gestation period of large hydro is long, commissioning to completion of a project takes 10-15 years. Large plants are usually far from the load centers necessitating long transmission lines that constitute huge losses. Currently large hydropower plants especially in Kenya and Tanzania are highly affected by climate change that has great variation in river waters. The plants do not generate to their full capacities all year round and most countries are turning to smaller hydropower plants for generation.

1.2.3 Kenyan hydropower technology S-Curve

Plotting performance of a technology against investment or efforts invested in it yields an S-curve. The S-curve can also be plotted on efforts (performance) or investment against time to give an idea of the technology advancement with time. It shows a technology trend and reviews if the technology or a product is in its emergence, growth or maturity stage for decision making to either; change, improve or abandon it.

Figure 8 below presents the Kenyan large hydropower technology s-curve as a computation of investment (installed capacities) against time over the years as well as planned installation for the year 2018.



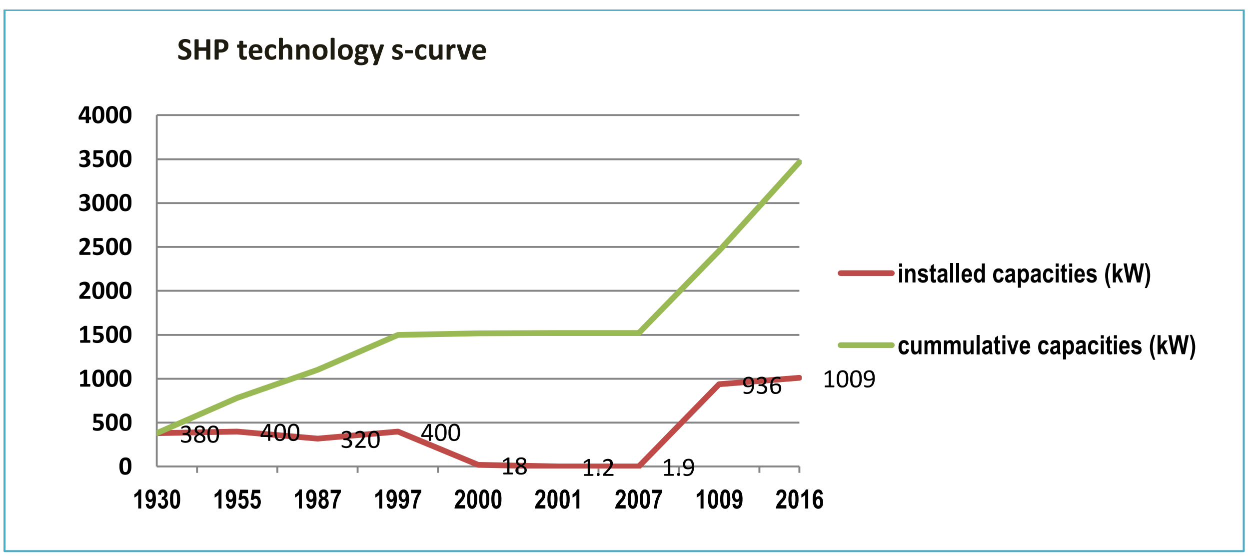
(Wikipedia, 2016)

Figure 8: Kenyan large hydropower technology S-curve

The figure above represents the Kenyan large hydropower technology s-curve. Large hydropower technology began in 1960's and gained rapid growth in 1980's. The technology reached maturity in 1999 after which development of large hydropower declined. This may be attributed to climate change that adversely affected hydropower in East Africa mainly Kenya and Tanzania. Hydropower development then shifted to small scale hydropower to effectively harness available energy.

In comparison, the Small Hydropower (SHP) technology s-curve is currently in its growth stage with majority of the projects being in feasibility study phase. Many of the proposed projects are owned by Kenya Tea Development Authority (KTDA) which has five SHP projects with a total installed capacity of 10.9MW under construction and expected to be completed by end 2016 (Ingram, 2015).

Figure 9 below represents the SHP s-curve of investment (installed capacities) against time:



(Wikipedia, 2016)

Figure 9: Small hydropower technology S-curve

From the above trend, small hydropower technology is in its growth stage and does not show and sign of maturity. The technology was in emergence stage until 2007 when it started to grow. The sharp gradient after 2007 indicates that the growth is in the early stages hence the technology can attract more investors for resource exploitation. This implies that there is need to evaluate the sustainability of these projects to have deeper understanding of their benefits to communities as well as economically to investors.

1.2.4 Future of hydropower

The future of hydropower is attractive with advancement in technology. Research and development is mainly directed in; hydrology, providing fish passage response, turbine modifications, water resource management, dam safety, monitoring tool and development. Currently major technology developments are emphasizing in areas as discussed below (U. S Department of interior, 2005).

- Uprating existing hydroelectric generator and turbine units as a cost effective means of generating additional power,
- Developing small power plants (low head and run-off hydro plants),
- Peaking with hydropower; best suited where demand vary along the day or over seasons. This is due to almost immediate start up or stop time.
- Pumped storage; stores power in form of water when there is a low peak demand. Over the peak demand, the water is utilized to generate electricity.
- Hybrid with other plants, intermittent resources like solar and wind energy can be tied to hydroelectric plant to improve their reliability and reduce demand on hydropower.

- Development of run off river and low head hydropower plants (less than 65 Ft head); high head plants provide higher power, however their development is limited by suitable site selection. Low head dams can be constructed to generated power near the centers where it is needed hence reducing transmission costs.

Pumped hydro is the most economic power storage available in the globe today. Mini hydropower plants have gained popularity for rural electrification in remote areas by micro- grid systems especially in Africa.

1.3 Micro Hydropower (MHP) in Kenya

Small scale hydropower is amongst the oldest environmentally sustainable energy technology. Micro hydropower is classified under Small hydropower and it is very currently very attractive in Kenyan for rural electricity access. Amongst all renewable energy technologies, SHP has the highest density resource and holds the first place in renewable electricity generation in the world (Surekha, Sinha, & Inamdar, 2005). Kenya being a tropical country has a huge potential for MHP generation, the estimated capacities for SHP potential is about 3,000MW.

In this research SHP has been used to refer to power plants of less than 10 MW installed capacity. MHP are those of up to 100kW and are commonly used to produce electricity for farms and villages (U.S Department of Energy, nd).

SHP plants can be classified as; Pico, micro, mini, and small hydropower plant depending on their capacities. MHP and SHP have been used interchangeably in this study since the former fall under SHP category.

In Kenya the classification of SHP is as shown on table 1 below.

Table 1: small hydropower classification in Kenya

SHP Category	Capacity (kW)
Pico	<5
Micro	5-100
Mini	100-1000
Small	1000-10000

(Muriithi, 2006)

Development of community based MHP in Kenya began in 2000 with the first plant at Tungu-Kibiri which was implemented for rural electrification. It is a projected funded by Practical Action Group and is run by the community. Since then, MHP has gained popularity with many people in a community forming a group to construct a shared plant. MHP electricity generation and distribution is mainly through an isolated or mini-grid within the remote communities.

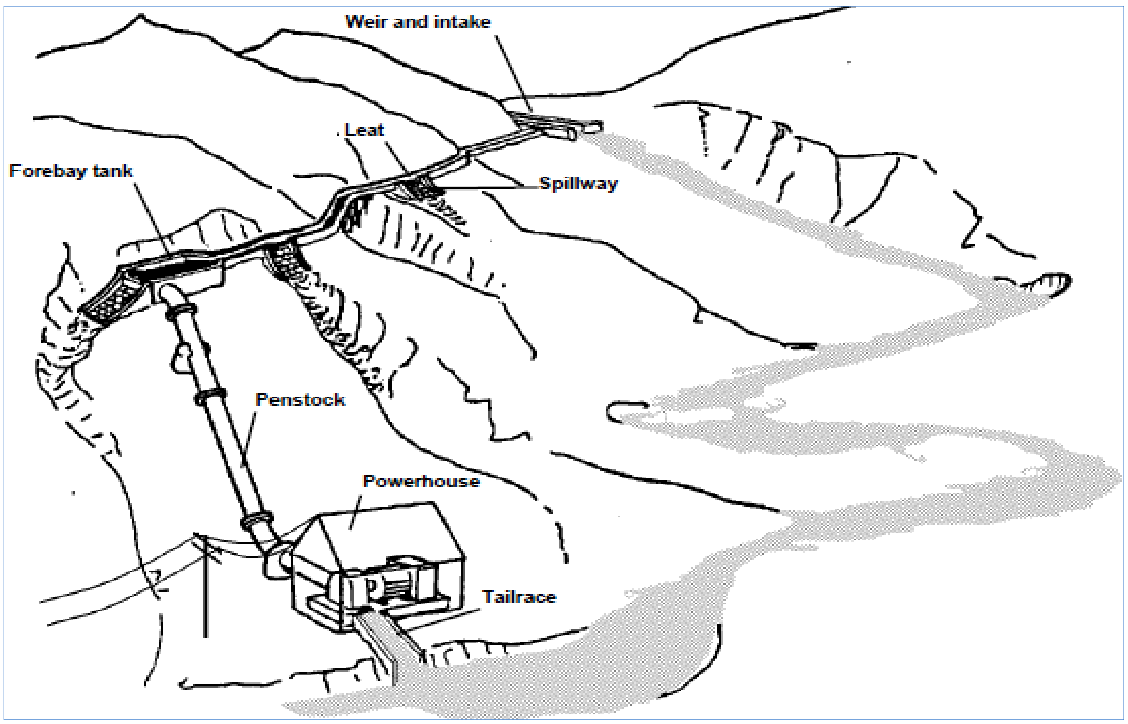
Mini-grids are small-scale electricity generation and distribution to a limited number of households or industry through an isolated grid. Currently mini-grids play a minor role in energy supply and electrification in Kenya. However, they are now gaining attraction for rural electrification and they are being promoted on the basis that they offer cost efficient, reliable and sustainable energy supply. The country has tremendous progress in installation of mini-grid; solar, wind small and micro hydropower projects. These projects play a major role in electrification, irrigation as well as addressing challenges in; technology, policies and institutional frameworks.

Micro hydro technology does not require a dam to harness the hydro resource thus it has minimal environmental impact. This fact has rendered the technology attractive to investors and national development on the bases of sustainability. The technology is currently popular in developing countries for electrification in remote areas. In developed countries MHP is commonly used to supply electricity to homes, farms and ranches (U.S Department of energy, 2004).

The main advantages linked to MHP are listed below (Nasir, 2013);

- High efficiency (70-90%),
- High capacity factor (more than 50%)
- Slow rate of change;
- Little vary in output on a daily bases: easily predictable;
- Quick start up or stop time and ability to make adjustments in the plant

Micro power plants are basically run off river power plants as shown in figure 10 below;



(British Hydropower Association, 2005)

Figure 10: Run of river diagram

The water from a river is diverted from the course through an intake at the weir. In high head installations, the water is then conducted to a forebay by a small channel known as a leat. The forebay slows the water for suspended particles to settle, it is also fitted with a trash rack to filter solid particles. A pressure pipe “the penstock” conveys the water from the forebay to the turbine.

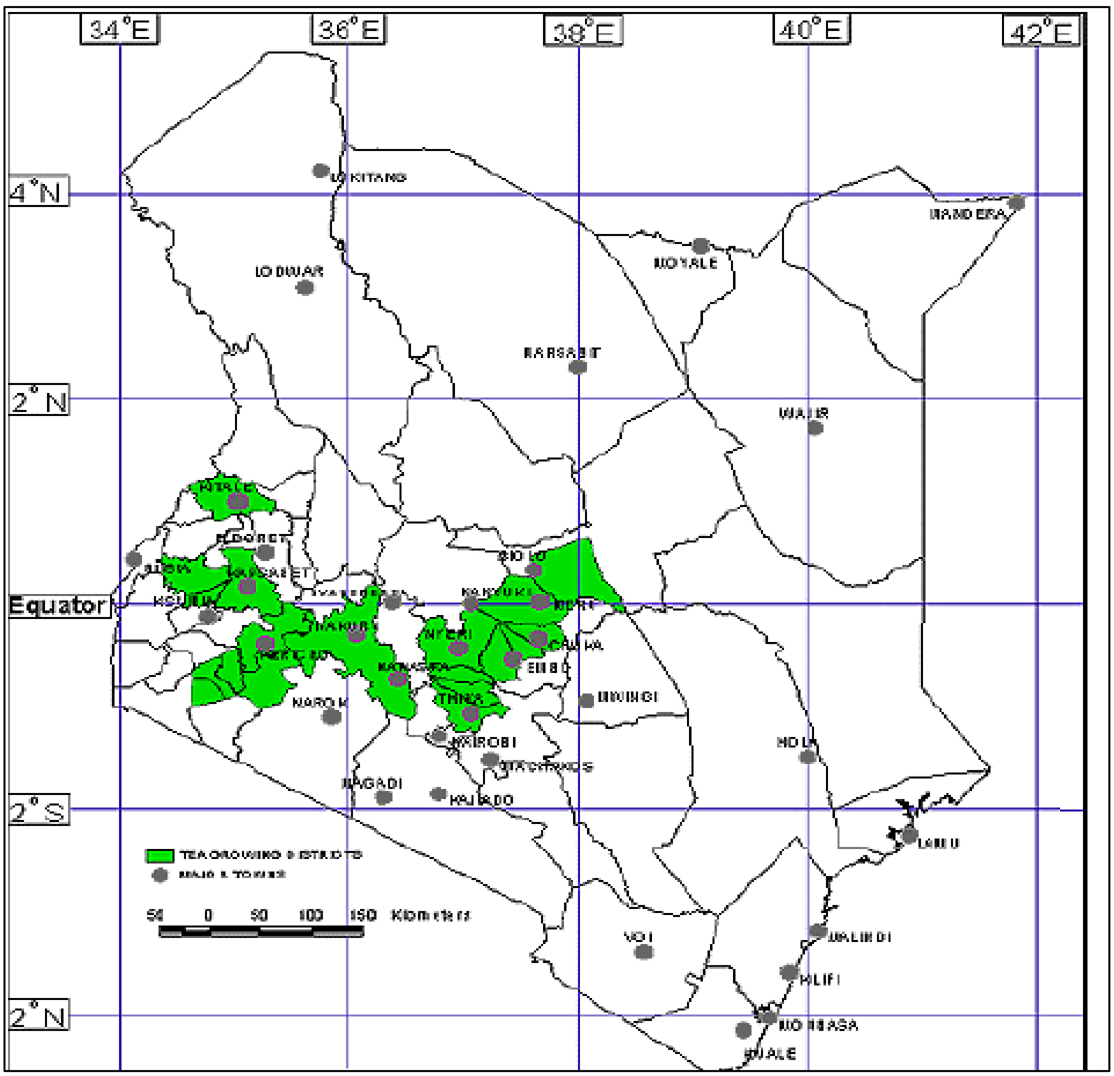
The water runs the turbine that is coupled to a generator, the water then returns back to the river course through the tail race.

This technology is simple, mature and cost effective on; operation, maintenance and the plants can be constructed using locally available materials. The major drawback in this technology is that runoff river plants are highly affected by seasonal variability of river flow. Hence, making it difficult to balance load and power output throughout the year (World Bank Group, 2006). This however can be eliminated by forming a hybrid plant with solar PV to reduce demand on hydropower over dry seasons.

Kenya has many rivers and streams in mountainous regions that make development of MHP highly feasible. SHP technology has lately gained popularity to harness the hydro energy in the country. The country's Small scale hydro potential is estimated at 3,000MW, of which less than 30MW have been exploited and only 15MW is supply the grid (Energy Regulatory Commission, 2014). Most of the SHP plants are private schemes owned by; local communities, missionary groups or Kenya Tea Development Authority (KTDA).

KTDA has been successful in implementation of SHP projects of less than 10MW. The association has established that there is a correlation between tea plantation sites and hydropower potential in the country. 80% of the association's tea factories (72) were surveyed and found to be within 3KM to 5KM of a potential hydropower site (Ingram, 2015). According to the Ingrams article in 2015, the association had proposed construction of 16 SHP plants with a total capacity of 23.33MW with feasibility study being done by Ministry of Energy in 14 other sites. This indicates an increasing demand in SHP in Kenya.

Figure 11 below shows Kenyan regions that have high potential for small hydropower generation. All the regions showed by the green color are densely populated mountainous regions and are tea growing zones. This renders it economically feasible for KTDA to develop SHP plants for tea processing as well as supply electricity to the communities within the tea factories. KENGEN has also developed some SHP plants of less than 10MW namely; Mesco, Wajir, Sossian, Ndula and Sagana power plants (KenGen, n.d).



(Antonio Fernández & Ali, n.d)

Figure 11: Small hydropower potential regions in Kenya

The major SHP operating schemes found in the regions shown above (Figure 11) are listed on table 2 below including their location, installed capacities and year of commissioning.

Table 2: Small hydropower plants in Kenya

Plant	Ownership	Location	Installed capacity (kW)	Year installed
Mesco	KenGen	Maragua	380	1930
Sosian	KenGen	Soaian	400	1955
Tenwek	Missionary Hospital	Bomet	320	1987
Imenti Tea Factory	KTDA	Imenti	900	2009
Diguna	Missionary	Diguna	400	1997
Tungu Kabiru	Community	River Tungu	18	2000
Mujwa	Missionary	Mujwa	7	
Thima	Community	Mukengeria	2	2001
Kathamba	Community	Kathamba	1.2	2001
Somorio	Community	Somorio	1.5	2007
Mitunguru	Community	Igoji	36	2009

(UNIDO, 2013)

SHP plants are expected to be the fastest growing small scale renewable energy technology in developing countries due to its abundance scope and proximity to rural population and habitants. The technology has great advantage to remote areas ranging from; electric power, improving the standards of living, enhancing education, public health facilities and employment.

Efforts in energy technologies are mainly focused in generation of affordable and reliable energy services for development and better standards of living. However, current energy harnessing techniques cannot be sustained if the technologies were to remain constant and supply more energy to satisfy increasing demand (Kucukali & Kemal, 2009).

Micro hydro has improved over time with low cost turbine designs, electronic load controllers, low cost penstocks by utilizing plastic (Department for International Development, 2000). Most of the projects implemented have help communities in terms of infrastructure development such as roads to school, enhanced livelihood of the habitants, health services, trade and improved agricultural sector.

1.4 Problem Statement

Electricity generation in developing countries of Africa is highly unreliable and characterized by acute power shortages and national grid connecting a small percentage of the population. Sustainability assessment of existing SHP projects has not been critically put into consideration resulting to inefficiency and poor performance in their later stages of the plants life cycle. Most of the countries have a total generated capacity of less than 1000MW against increasing electricity high demands (Kaunda, Cuthbert, & Torbjorn, 2012). The major weakness encountered by most micro-hydro schemes in developing countries is very low load factor, often less than 25%.

Kerosene lamps are majorly used for lighting in areas without access to electricity. The main demand for electricity in rural communities is lighting which accounts for about two hours in the morning and three to four hours at night. The overall load on the generator only reach its design capacity over this period. The demand for power for the rest of 18 hours a day is very small. Utilization requires improvement to balance energy demand during peak and low peak as well as to accommodate increasing energy needs for efficient utilization of generated power.

In Kenya, micro hydropower has been commonly used in the past decade to generate electricity in communities for domestic, hospitals and other small scale services. However, these projects have experienced major problems due to lack of future demand projections leading to conflict with current increase in electricity demands. Secondly, most of the projects are now viewed to be of little use because the national grid has currently reached some rural region. Thirdly, some projects collapsed and abandoned due to lack of efficient maintenance and thus the community perceives them to be ineffective.

This research assesses the sustainability of micro hydropower plant projects installed for rural electrification using a set of energy indicators for sustainable development. Assessment was done by conducting case studies of several micro hydropower projects in different regions of Kenya. In the research the performance of the plant was assessed as well as the economic, social and environmental impacts of the project to the region.

1.5 Research Questions

1. What are the main challenges to sustainability of community-based micro hydropower projects?
2. How does the sustainability of private hydropower plants compare to that of community-owned plants?
3. Is hydropower more sustainable than other renewable technologies available for electricity access in remote areas?

1.6 Objectives

i. To develop a suitable model of energy indicators for assessing sustainability of micro hydropower projects in Kenya.
ii. To assess and rank sustainability of Kenyan community micro hydropower projects in comparison to private hydropower projects.

iii. To compare the sustainability results of micro hydropower plant to those of other available renewable energy technologies for rural electricity access: Solar Home System (SHS).

1.7 Hypothesis

Micro hydropower projects provide the most sustainable renewable energy technology for electricity access to remote communities when properly maintained.

1.8 Scope of study

This research investigates sustainability of community micro hydropower projects in Kenya based on open ended interviews. The study first reviews the Kenyan energy situation and the renewable energy potential with main focus in hydropower technology on sustainability concept. The literature review includes study analysis of major sustainability assessment models that have been developed by various organizations and individual authors. In the methodology, a suitable sustainability model for assessing community based energy systems was developed. The model was then applied assess the sustainability MHP projects and a SHS.

The areas of study included eight hydropower sites, six of which are community based MHP projects, and two private owned hydropower plants. The selection of the sites was on location bases so as to cover each potential region of the country. MHP plants are mainly concentrated in the central province, eastern province and some parts of the Riftvalley province in Kenya. The study was focused on these three regions with a pilot study on Tngu-Kabiri MHP project. One PV solar home system was also evaluated to help compare the results of sustainability to those of MHP projects.

1.9 Need for sustainability in hydropower projects in Kenya

Kenyan energy sector is characterized by heavy petroleum import and overdependence in biomass (wood fuel). In 2008 alone, oil import accounted for 55% of the country's foreign exchange from imports (Kiplagat, Wanga, & Li, 2011). Currently there is tremendous land degradation due to pressure on forest and stock vegetation in quest for wood fuel. There is huge potential to develop and harness energy from available renewable resources in a sustainable way to save on import cost as well as the environment. This will involve participation of private sector as well as the government and communities to work together towards a sustainable future.

Sustainable growth for economic development requires combination of reliable energy input from all available resources. These resource harnessing systems should maintain a balanced ecosystem during exploitation and energy use. The development trend for SHP in Kenya shows that the technology is in its growth stage hence there is essential need to ascertain that the systems are sustainable. This will save the environment and also the cost of generating energy by considering expectations for new energy options as well as existing plants.

Large hydropower generation in Kenya contribute to 30% of electricity demanded. The hydropower plants are concentrated on the eastern part of the country which is far away from the load centers. The transmission lines are long and huge losses are incurred in T&D of electricity. Such plants are further criticized on sustainability basis due their advance environmental and social impacts such as:

- Resettlement and migration of affected population
- Building of large dams to create reservoirs
- Disrupting cultural activities of habitants such as fishing
- Deposition of silt in rivers

- Emission of GHG from the reservoirs
- Disruption of hydrology down the river

Currently Kenyan large hydropower plants are highly susceptible to seasonal variation of water levels in rivers and reduction in reservoir capacities due to siltation. Most of the plants have their capacities reduced by more than half in dry seasons leaving most part of the country in darkness (Kiplagat, Wanga, & Li, 2011). For sustainability this calls for improvement of the technology to maximize energy harnessing and environmental goals to help curb climate change. Large hydropower is still economically viable for African countries. However, sustainability to balance ecosystem and social factors has to be carefully put into consideration. This will require policies and regulation for exploitation of resources to avoid conflicting with international laws.

Development of SHP has gained acceptance on sustainability basis, the plants are considered to be sustainable ecologically, environmentally and economically. However, this does not mean that there are no efforts required to monitor their sustainability. There is need for their continuous evaluation and monitoring in all the phases of: potential assessment for new hydro options, assessment of new plant and assessment of performance of existing plant (International Hydropower Association, 2006). Sustainability assessment helps to review whether the plant is functioning without compromising the comfort of the society and the environment. The results may establish if there is need to chance or upgrade the existing technology to match sustainability requirements.

According to the best practice for sustainable development of micro hydropower in developing countries, 2000 report, promoters of these types of projects only justify the success based on social justice, quality of life to marginalized people and to the environment. The report indicates that there is lack of documented information on; capital and operation costs or cash flow returns on the investments that could be reliable for potential investors and financial institutions. These facts reveal micro hydropower projects to lack or have limited sustainability especially those implemented for community development.

Kenya SHP development is in the growth stage, most micro hydropower projects have sprout up within the last decade. This brings the need to assess their sustainability to ensure proposed, new and existing plants conform to sustainability goals to maximize utilization as well as to cater for future needs. The main challenge facing existing SHP in Kenya is the abandonment of the project when the grid electricity finally reaches the location. Secondly there have been conflicts within the community causing some people to leave the project. Lastly some projects have failed due to lack of proper maintenance and the community lender them non-performing due to lack of proper knowledge. Continuous sustainability assessment of these projects would help eradicate these problems. The management can be advised on areas to adjust for smooth running of the project as per installation expectations.

The need for continuous evaluation of performance and assessment of MHP projects sustainability can be presented as a SWOT analysis as shown in the figure below.

Table 3: Micro hydropower SWOT analysis

Strength - Mature technology - Cost effective; capital cost, O&M costs - Environmental friendly - Long lifespan - Favorable financial support: NGO funding	**Opportunities** - Enormous potential - Attractive for rural electrification - Favorable for; Micro-grid, smart-grid - Favorable Kenyan policies for MHP development Energy Act 2006 and feed in tariff 2008)
Weakness - Under exploited resource (only 30%) - Low conversion efficiencies 50% - Low load factor; Majorly used for lighting - Lack of preservation and conservation measures - Lack of documentation; performance, economic analysis, data.	**Threats** - Abandonment due to arrival of national grid - Poor monitoring, maintenance and repair by community leading to project failure - Communal conflicts - Increasing demand due to increasing needs and population

From the above SWOT analysis, it is evident that there is need for sustainability assessment and intervention mainly in; social, economic and technical dimensions for the community projects to function smoothly. Sustainability assessment is a necessity in all stages of a project, feasibility, implementation, operation and monitoring. Sustainability is a tool for all the stakeholders involved not only to management since these are community based projects and the local inhabitants have a great role in the project. They need to understand how the project runs and what is expected of them for smooth performance.

CHAPTER TWO

2.0 LITERATURE REVIEW

Energy is the central factor for achievement of sustainable development. Current patterns of energy generation, transmission, distribution and utilization are unsustainable (UNDP, 2004). Renewable Energy Systems (RES) have low environmental pollution and are considered as a criterion to mitigate climate change. RES are sustainable compared to conventional energy systems in terms of environmental consideration as well as their ability to be decentralized for rural energy supply.

According to the UNDP 2004 report, to supply reliable and affordable modern energy services to a third of the global population that lacks electricity access, new measures have to be enacted. The measures should address; energy efficiency, use of renewable energy, regional and international cooperation, and use of appropriate technology in various locations. These measures guide nation’s development towards sustainable energy supply however the challenge lies in assessing the sustainability of the systems.

Indicators for sustainable development were recognized by Earth Summit, 1992. Countries were urged to develop indicators to help them evaluate their development towards sustainability. Sustainability was thereafter given great relevance in subsequent summits mainly; the ninth session of the Commission on Sustainable Development (CSD-9) and the World Summit on Sustainable Development (WSSD) in 2002. Since 1999 International Atomic Energy Agency (IAEA) developed energy indicators for sustainable development. In 2002, IAEA was recognized as the initiative official partnership of WSSD. Many countries and organizations have adopted these indicators or developed their own based on the IAEA indicators to assess their progress.

Energy indicators are not just statistics, they provide deeper understanding of an existing relationship between the; environment, ecology and economy that may not be evident in simple terms (Ivan & Lucille, 2006). Indicators provide a clear picture of a whole system and its linkage with other aspects. They help policy and decision makers to evaluate the system and its implications over a period of time to ascertain if it is worth to undertake or reject it.

In this paper sustainability is the ability of a hydropower plant to maintain its designed operation and provide projected services and benefits throughout its life span.

For a technology to be sustainable it should fulfill the following objectives of sustainable energy development (Surekha, Sinha, & Inamdar, 2005).

- Contribute to economic growth of the region by enhancing trade and creating employment;
- Be cost effective on basis of: fuel cost reduction, cost of technology development, transmission cost and cost of capacity building;
- Ensure security of energy supply for current and future needs;
- Have maximum efficiency of utilization and focus on renewable energy;
- Promote energy conservation at generation and by end user;
- Maintain local ecosystem quality and minimize greenhouse emissions and other pollutants;
- Be acceptable to the community, enhance unity and improve the population’s standard of living.

2.1 Sustainability Indicators Models

Over the years since sustainable development became a global goal every sector of development is now driven towards implementing sustainable system. Sustainability currently directs future investments, policy development, funds allocation and private sector participation. In energy sector and systems it is now a norm to use sustainable indicators to assess the impacts of each stage of the supply chain cycles either on; environment, social, technical and economic aspect. Several models on how to assess sustainability of various systems have emerged based on different organizations, institutions, authors and countries. However, no given set of energy indicators can be taken as definite and final. The models are based on development of sustainable, affordable and reliable energy services based on given sets of dimensions.

This chapter reviewed the available models of Energy Indicators for Sustainable Development (EISD) highlighting their dimensions, strengths and drawbacks. Finally a model was developed with suitable indicators for assessing sustainability of micro hydropower plants.

2.1.1 Energy Indicators for Sustainable development (EISD) Model

This model was developed by International Atomic Energy Agency (IAEA) and adapted by the world summit on sustainable development in 2002 as a guide for sustainable assessment. According to this model for an energy system to achieve sustainability, continuous monitoring of impacts towards development is compulsory. It is of great help in evaluating whether the system is contributing towards sustainable development or it should be adjusted. Energy indicators were thus developed as guidelines for addressing issues within three major dimensions of sustainable development (IAEA, 2005). These energy indicators guide policy makers on key issues such as:

i. Know countries current status concerning energy and economic sustainability: what needs to be improved and how,
ii. Understand the implications of selected energy, environmental and economic choices, policies and plans and their contributions towards sustainable development,
iii. Know the methods for measuring effects of energy use on human health, society, soil and water,
iv. Determine whether current energy use is sustainable or not.

IAEA provides 30 EISD based on three pillar dimension (economic, social and environmental) and classified into seven themes and 19 sub-themes. Each indicator was derived from the sub-theme and it expressed aspect of energy production and use. The themes and sub-themes as shown on table 4 below:

Table 4: IAEA energy indicators model

Dimension	Theme	Sub-themes
Social	Equity	Affordability accessibility disparities
	Health	Safety
Economic	Energy use and production patterns	Overall use overall productivity supply efficiency production end use fuel mix prices
	Security	Imports strategic fuel stocks
Environmental	Atmosphere	Climate change air quality
	Water	Water quality
	Soil	Soil quality Forests solid waste generation and management

(IAEA, 2005)

The main advantage of the energy indicators provided by IAEA is that they are suitable for assessing energy systems and tracking their progress towards national or institutional goals. They are suitable for policymakers and help them to determine if current energy systems are sustainable or there is need to change the technology. The main setback of these indicators is that they are complex, difficult to interpret and do not provide concise general overview of a system behavior (Angelis & Arampatzis, n.d).

2.1.2 UK Energy sector indicators model

This model was developed by United Kingdom statistics authority to evaluate energy use, and supply, emissions, fuel prices, fuel poverty and competition. The indicators model was based on four dimensions from which eleven sub-groups are formed. These indicators help to develop statistics that; meet identified user needs, are well explained and accessible and objective for public interest (UK/DECC, 2014). The categories and sub-groups are as indicated in the table 5 below:

Table 5: U.K energy sector indicators model

Dimension	Sub-group
Economic indicators	Energy in the economy; investment and productivity
Reliable supply of energy	Resources
	Energy intensity
	Capacity utilization
	International comparisons of energy productivity and use
Energy prices and competition	Fuel prices(industrial, and oil & petroleum
	Competition in energy market
	Fuel prices (domestic)
Environmental objectives	Conversion efficiencies
	Energy use indicators
	Energy and the environment

(UK/DECC, 2014)

The main advantage of this model is that it clearly gives a wide range of data required to provide a snapshot of the energy sector/system under investigation. Data for the energy system can be easily computed to give statistics based on the indicators. However, this can be a great challenge in nations that have inadequate data of energy systems. Full potential of most developing countries is an estimate and lack of data especially in Africa limits application of the model. The model also lacked clear indicators to show relationship between the energy systems and the society and how poverty eradication can be assessed by the model.

2.1.3 Sustainable energy indicators for renewable energy systems

This model was developed by Annette Evans, Vladimir Strezov and Tim J. Evans in 2008 for assessing sustainability of renewable energy systems. The model used a range of indicators that the authors found to be important for evaluating energy generation technologies. It used six dimensions based on how; environmental, human social and economic aspects are impacted by the choice of production method (Annette, Vladimir, & Tim, 2008).

This model's indicators for sustainability assessment are listed below;

- Price of electricity generation unit
- Greenhouse gas emission
- Efficiency of energy transformation
- Land use requirement
- Water consumption
- Social impacts; acceptability of technology, human risk and consequences

The authors used the indicators on each renewable energy technology assigning the indicators equal importance. From the evaluation, wind power was the most sustainable followed by hydropower, solar PV and then Geothermal.

The model was simple and suitable for assessing and ranking different technologies as well as different projects of the same technology. However, the model was mainly focused on energy generation and did not constitute energy use, end use or supply efficiencies which are key factors in an energy cycle.

2.1.4 Sustainable energy policy indicators

This framework model was developed to propose clear and operational indicators for policy makers, analysts and citizens to assess sustainability (Konstantinos, Haris, Argyris, & John, 2007). According to the authors, for a given model to be suitable it should fulfill following objectives;

- Appropriateness; realistic description, transparency, simplicity and ability of comparison,
- Completeness; technical and scientific adequacy, international acknowledgement,
- Flexibility; ease of calculation, existence of right quality data, ability of mapping changes and ease of connecting with other models.

The framework provides three main dimensions using the above set of objectives as the section criteria for the indicators. The three dimensions are; security of energy supply, competitive energy market and environmental protection. These dimensions and the indicators are grouped as shown on table 6 below;

Table 6: sustainable energy policy indicators model

Security of energy supply	Competitive energy market
Dependence on imports	Energy intensity

Dependence on imports of solid fuels	Efficiency of energy conversion
Dependence on imports of oil	Efficiency of electrical energy production
Dependence on imports of natural gas	Transformation of energy sector
Differentiation of primary fuel	Level of competition
Differentiation of fuel of electrical energy production	Per capital energy consumption
Differentiation of energy fuel	Per capita electrical energy consumption
Strategic oil supply	
Environmental protection	
Percentage of renewable energy source in primary energy production	
Percentage of renewable energy source in primary electrical energy production	
Intensity of Co_2 emitted	
Application of Kyoto protocol	

(Konstantinos, Haris, Argyris, & John, 2007)

The model presented variables that were easy to measure and weigh especially when comparing projects in different regions. It however did not provide detailed criteria to evaluate the economic value of the systems such as the cost of energy and the social benefits generated by the system.

2.1.5 Sustainability in hydropower development

This model was developed to evaluate to assess the sustainability of three hydropower projects in a case study in China. The authors; Jian, Zuo, Zhiyu, Goerge, and Chen applied the protocol developed by the International Hydropower Association as a guide to assess the social, economic and environmental impacts of hydropower in China.

The sustainability indicators criteria used in the framework is sown on table 7 below;

Table 7: Sustainability indicators model (India)

Social	Economical
Reduce poverty and enhance quality of life	Capital cost and recurrent costs
Equitable distribution of benefits of project	Savings on GHG emission and improved air quality
Effectiveness and ongoing compensatory and benefits	Payback period
Public health	
Impact of displacement on individual and community	
Community acceptance	
Protection of cultural heritage	
Environmental	
Air and water quality	
Waste management	
Sediment and transport emission	

Downstream hydrology and environmental flows Rare endangered species Passage of fish species Pest species within the environment Health issues Impact of construction on aquatic and terrestrial environment Adoption of independent audited environmental management systems

(Jian, Zuo, Zhiyu, George, & Xianming, 2012)

The framework was extensive and captured the three dimensions. However it did not include the energy production, conversion efficiencies, resources and use. The authors concluded that sustainability goes beyond the three pillar concept of economic, ecological and social aspect and extends to government policy and cooperation, R&D and system approach. These aspects were not captured by the model and are very crucial in sustainability of projects. More frameworks are being developed to assess more dynamic aspects of sustainability in all levels.

2.1.6 Sustainability indicators of power production systems

This model was focused on sustainability based on delivering uninterrupted energy supply to consumers in economical way considering the social and environmental impacts (Nevzat & Haydar, 2010). The framework applied six dimensions which were subdivided into 23 subgroups with a total of 60 indicators. The dimensions and subgroups are as shown below;

Table 8: Sustainability indicators of a power production system

Political and economy environment	**Resource environment**	**Social influence**
Social political condition Microeconomic situation	Natural resource available Environment being limited	Just distribution benefits Employment benefits Economy benefits Cultural influence Cultural security
Comprehensive competition	**Market environment**	**Environmental influence**
Operation and performance	Supplier's bargaining ability	Air emission

Technical level	Buyer's bargaining ability	Solid waste
Human resource	Competition from industries	Water pollution
Technical innovation management	Threats from substitutes	Noise pollution
		Ecological impact

(Nevzat & Haydar, 2010)

The model was exclusive and captured all the dimensions from; political, economic, technical, environmental, and social to market. It was business oriented and suitable for assessing profit gain from a given energy system and hence its contribution towards economic development. However, the model did not account for follow-up on energy use by the end user which is essential for a community set up.

2.2 Related research

Various researches have been done worldwide to evaluate sustainability of hydropower projects. Many authors have examined such projects based on their models to highlight the projects benefits as well as their shortcoming.

Dwarika Adhikari, 2011 assessed the sustainability of micro hydropower plants in Nepal where such projects are economical for rural energy access. In his research he adapted the International Hydropower Association (IHA) guidelines for hydropower sustainability assessment. In his findings, the hydropower assessment scored 3.61, which indicated that the plants were at a sustainable level however, good governance and political backing would help improve the sustainability score. His research provided an insight of how to evaluate sustainability using IHA guidelines.

In 2009, Shradha Upadhuyay evaluated the effectiveness of micro hydropower projects in Nepal. In his research he developed a model of 20 indicators that were used to evaluate and compare two micro hydropower projects; Luwung Ghale, 44kW and Ghandruk 50kW. The two MHP community projects served 272 and 227 household respectively.

In his findings he reveals the major challenges faced by the MHP projects as; social, managerial, financial and technical constrains. He urged that for such projects to be sustainable there is need for greater support not only in setting up the hydropower plants but also in technical training and monitoring as well as better policies on subsidies and seat equity.

In 2014, Deepak and Katoch developed a model for assessing the sustainability of ROR in India. In their research they used a model with three main dimensions based on the three pillar concept of sustainability and 49 indicators. The indicators were further sub grouped as; qualitative, quantitative, direct impact or indirect impact on sustainability (Deepak & Katoch, 2014). Quantitative (tangible) indicators are those that can be measured by a reliable unit while qualitative (intangible) indicators are those impossible to assign a measurable unit for example; a community standards of living.

The model developed is suitable for policy makers and planners to develop sustainable hydropower projects and to evaluate existing ones to determine their compliance with sustainability customs. However, they did not test the model to show how it would be used to provide sustainability results for the county.

Various researches have been done in Kenya on SHP assessment. However, there is a missing gap in assessment of sustainability of the technology in the country. Off-grid electrification option has been recommended for energy access to rural communities to utilize the available renewable energy resources (Maher, Smith, & Williams, 2002). In their research, Maher, Smith and William compared the use of SHS and Pico hydropower for rural electrification. Their findings revealed that both technologies are faced with technical challenges especially in installation and choice of appropriate design. Use of Pico hydropower was preferred to use of SHS mainly on economic analysis and due to cloud cover in mountainous regions. This research revealed the point of weakness in design of these two technologies and the best way to implement them.

CHAPTER THREE

3.0 METHODOLOGY

In sustainability, assessment is the act of evaluating and rating an analysis of; needs, system and impacts. This is however faced with many challenges mainly because sustainability itself cannot be a direct measure and the approaches used differ from one institution to another. This chapter assesses the sustainability of community based micro hydropower projects implemented for electricity access. The sustainability evaluation is mainly based on the effectiveness of the power plant to generate reliable and affordable energy and energy services for improved social standards and environmental protection.

This study adopted descriptive research methodology in that quantifiable data was collected using closed ended questionnaires. It reviewed and measured the strength of selected micro hydropower projects to understand the trend and progress of such technologies. The research is of great help to organizations that mainly fund such community based project since it provides insightful information on progress and significance of the projects to rural communities.

The research aimed at evaluating the sustainability of micro power plants using a sustainability indicators framework developed by selecting and combining most suitable indicators from different authors. The model developed was mainly guided by the three pillar concept of sustainability and some measurable indicators that evaluate the performance of the energy system. The results of the micro hydropower projects sustainability were then compared to those of solar home system used for rural energy access.

Various approaches were applied in the evaluation. The main approach that was taken in this research was the three pillar concept of sustainability that assessed the projects based on; ecological, social and economic criteria. The concept applied both quantitative (tangible) and qualitative (non-tangible) analysis. The quantitative indicators are measurable by a reliable unit, for example power plant capacity or energy generated. On the other hand qualitative indicators are impossible to define or measure by a reliable unit for example, living standard of a community and visual impact (Deepak & Katoch, 2014).

The IHA provided a set of guidelines for assessing sustainability of new energy supply options, new and existing hydro projects in regards to economic, social and environmental aspects (International Hydropower Association, 2006). The three dimensions were sub grouped into 20 aspects that are used to assess and rank sustainability of hydropower projects. The aspects for assessing a new hydro project are presented on the table below:

Table 9: International Hydropower Association indicators model

No.	aspect	No.	aspect
A1	Political risk and regulatory approval	A11	safety
A2	Economic viability	A12	cultural heritage
A3	Additional benefits	A13	Environmental impact assessment and management planning
A4	Planned operational efficiency and reliability	A14	Threshold and cumulative social and environmental impacts
A5	Project management plan	A15	Construction and associated infrastructure impacts
A6	Site selection and design optimization	A16	Land management and rehabilitation
A7	Community and stakeholders consultation and supply	A17	aquatic biodiversity
A8	Social impact assessment and management plan	A18	Environmental flows and impact management
A9	Predicted severity of social and economic impact on directly affected stakeholders	A19	Reservoir and downstream sedimentation and erosion risk
A10	Enhancement of public health and minimization of public health risks	A20	Water quality

(International Hydropower Association, 2006)

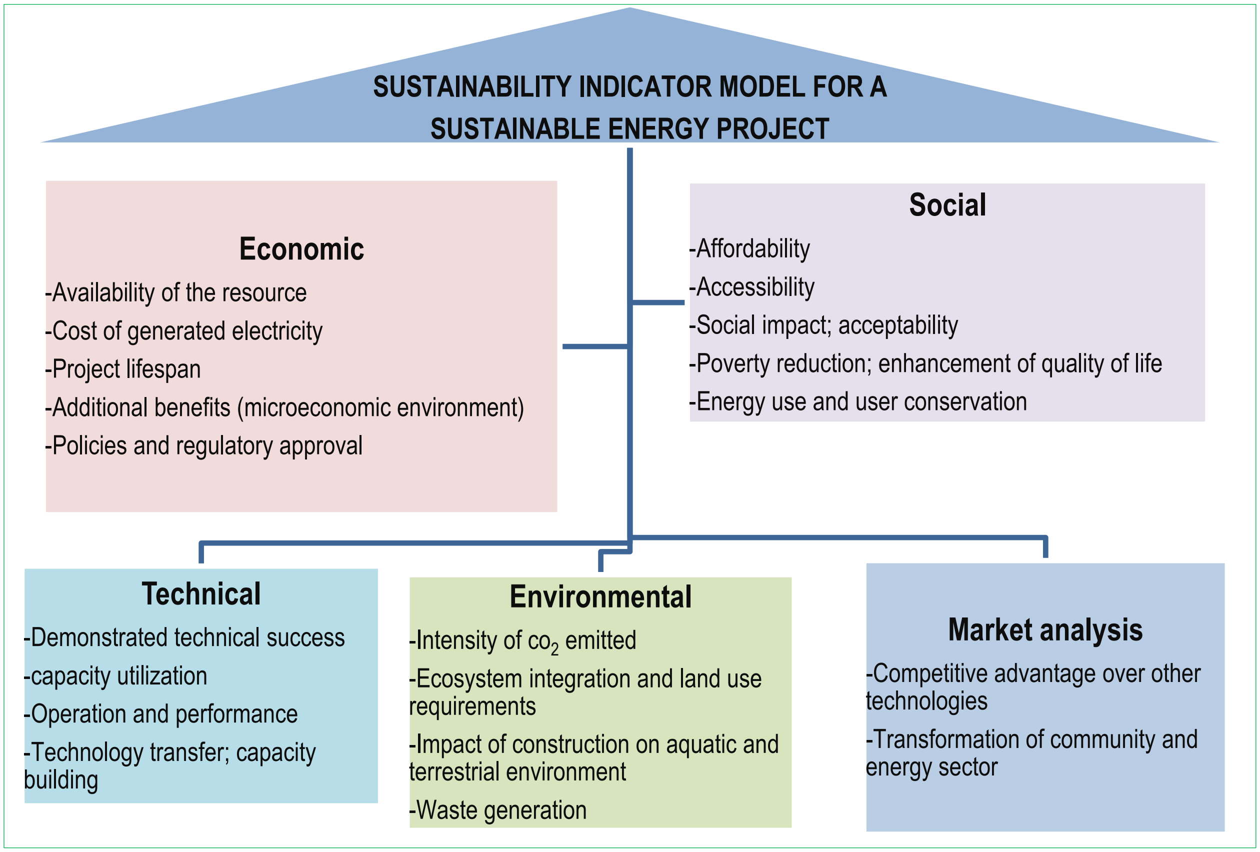
This guide helps individuals/members to assess sustainability by ranking performance against criteria developed by IHA. The assessment relies on objective evidence score portrayed by hydropower system against each of these 20 aspects as recommended by IHA.

3.1 Proposed framework

The model applied for assessment in this research consisted of five main dimensions namely; economic, social, environmental, market and technical. The dimensions were then sub grouped to form 23 main sub-dimensions from which 66 indicators were developed to assess the sustainability of the energy projects. The aim of developing the model was to come up with a framework that could be used to assess hydropower plants and at the same time applicable for comparison with solar home system or any other renewable energy technology.

It was a combination of suitable dimensions and sub dimensions from international models and individual author's models to develop a framework that was easy to apply and understand. The framework is presented on the table 10 below;

Table 10: Proposed Indicator Model



The model was presented as an umbrella for indicators used to access sustainability of an energy system. The framework was developed from a combination of dimensions and sub-dimensions from models previously discussed in chapter two of this research since no single model was suitable for the assessment on its own. The selection of the indicators was guided by the suitability for community based projects evaluation in remote areas and the projected energy accessibility and use. The main aim of the choice of dimensions and the indicators was to develop a model that was focused on all essential factors of sustainable energy generation systems for renewable energy exploitation following IHA guidelines. Therefore, the model can be used to evaluate other energy systems such as; solar, wind, geothermal and bioenergy technologies for comparison.

Economic dimension;

This dimension assessed the development progress of the community as a result of the project implementation. For continuous economic development was the key indicator of sustainability. In this research the monetary benefits generated by the project were evaluated by calculating returns on electricity and other business developed by the energy project.

the project financial analysis were evaluated using deterministic approach that relies on data collected on the market and discounted cash flow rates (Cunha & Paula, 2014). The analysis were used to determine the Levelized Cost of Electricity (LCOE), payback period and cost benefit ratio of the micro hydropower project using MS. Excel sheet.

Social dimension

This dimension assessed the community wellbeing as a result of how the habitants benefit from access to modern energy services provided by the hydropower project. This dimension is not measurable and hence it is reliant on the population view point and can be biased. It looked into community quality of life transformation, acceptability of the project, equity of energy services and the affordability of the services. For sustainability the society has to feel connected to the energy projects and the project to run smoothly by upholding the cultural heritage of communities and without any conflicts.

Livelihood approach analysis was used to determine the effects of electricity on the community's households and living standards. The approach relied on the community diversification improvement base on asset acquisition. For example; buying television set, entrepreneurship enhancement (like hair styling), employment creation and development of infrastructures.

Impact on education was also be used to assess the social development of the region; it reviewed how much the project had enhanced education standards of the students. Contribution of the project to gender equality was also assessed on the basis of how the girl child livelihood was enhanced by electricity access.

Environmental dimensions

This dimension was based on ability of the energy generating system and utilization to uphold the environmental without or with minimal pollution. Is assessed the co-existence of the system with the ecosystem and mainly on; GHG emission, the impact of construction on habitants and organisms, and waste generation and disposal. The environmental dimension was very crucial to sustainability since it is the factor that regards renewables more sustainable compared to fossil fuels on the basis of CO_2 emissions.

A sustainable hydropower energy system has to enhance the ecosystem by conserving the Fiona and fauna and avoids tempering with the hydrology flow of the river downstream.

Technical Dimension

The indicators of this dimension evaluated the technical ability of the energy system to supply reliable energy to the community as demanded. It is a measurable entity that assesses the plant load factor, capacity factor, efficiency and electricity generated annually. Data of the river flow, electricity generation, utilization and demand was essential for performance evaluation. This enabled the management to know whether the plant is functioning as it was supposed or there were some diagnostic problems that needed attention. The ability of the community to run the project without external intervention was also evaluated. For a hydropower, poor technical performance could be an indication of poor maintenance since the plants have long lifespan.

Market analysis

This dimension unlike the others assessed the sustainability of the project in respect to external factors. It evaluated the competitive ability of the power production system to perform better than other technologies available in the community. It also compared the level that the project had elevated the community compared to the neighborhood that lacks such energy facilities. The dimension looked into threat from other technology substitutes and how the energy project integrated with other development programs within and outside the community. It is essential to derive ways in which community based projects remain relevant and competitive especially when the national grid reaches the remote areas in future. Some hydropower projects have been faced with rejection when grid connection reach the community while some still perform better even in presence of national grid.

3.2 Proposed sustainability indicators

The indicators developed to assess the sub-dimensions were developed based on a criterion to ease assessment of energy systems in a rural setting. They are simple to apply and comprehend for individuals or groups that intend to curry out sustainability studies in community based projects. The indicators used to assess the sub-dimensions for sustainability are shown below (Table 11).

Table 11: Proposed sustainability indicators

Economic Dimension			
Sub dimension	Indicator		Score
Availability of the resource	A1	Availability of the resource throughout the year (output not affected during dry seasons)	
	A2	Appropriate head and design for generated electricity	
	A3	Plant installed capacity to generated capacity ratio	
Cost of generated electricity	A4	Capital cost and recurrent (O&M) costs Vs. gross revenue	
	A5	Levelized cost of electricity (LCOE)	
	A6	Cost/benefit ratio	
	A7	Planned monitoring of project economic performance	

	A8	payback period	
Ability to serve Projected life	A9	Frequency of main components breakdown	
	A10	Upgrade expected within its life cycle	
	A11	Lifespan of major components (turbines, generators and penstock)	
Additional benefits	A12	Business opportunities created by the project: monthly income generated	
	A13	Job creation (direct and indirect employment opportunities)	
	A14	Additional amenities (roads, hospitals, schools)	
	A15	Enhancement and improvement in agriculture sector	
Policies and regulatory approval	A16	Certification of project by regulation authorities	
	A17	Project compatibility with laid social, environmental and energy policies	30%
Social Dimension			
Sub-dimension		Indicator	Score
Affordability	A18	Percentage of project members able to buy electricity from the project	
	A19	Ability of the members to pay for the monthly billing	
Accessibility	A20	Ease of transmitting the micro-grid to the project members	
	A21	Ability to extend the micro-grid to new entrants to the community	
Acceptability	A22	Conservation of historic and indigenous heritage values	
	A23	The communities will to pay for electricity consumed	
	A24	Stakeholders consultation, support and involvement in project activities	
	A25	Existence of complains and conflicts about the project by the community	
Poverty reduction (enhancement of quality of life)	A26	Community livelihood improvement (assets: TV, radios, phones, hotels)	
	A27	Significant increase in public health, water quality and education	
	A28	Gender balance enhancement (improvement of women/girls' life)	
Energy use and user conservation	A29	Flexibility of electricity use other than lighting	
	A30	Awareness of community on energy saving and conservation methods	
	A31	Energy saved and equity in use of energy saving bulbs and appliances	30%
Technical Dimension			
Sub-dimension		Indicator	Score
Demonstrated technical success	A32	Demonstrates good design of the systems: intake, penstock, powerhouse	
	A33	Efficiency of the machinery: turbine and generators	
	A34	Minimization of losses by networking assets (transmission and distribution)	
Capacity utilization	A35	Satisfies the energy demanded by the community (load curve)	
	A36	Plants capacity factor	
	A37	Plants utilization factor (usefulness of installed capacity)	
Operation and performance	A38	Reliability of the generated electricity (number of breakdowns in a month/year)	
	A39	Availability of planned maintenance program and duration of shutdown	
	A40	Mechanism for load control during peak and off peak demand	
	A41	Safety mechanism for the plant; control panel, emergency shutdown, spillways, flood controls	
Technology transfer and capacity building	A42	Ability of the community to run the plant without external personnel intervention	
	A43	Planned training for plant operators	
	A44	Evidence of replication of project to neighboring villages	
Safety issues	A45	Planned compensation/mitigation program for stakeholders (flooding, accidents)	
	A46	Planned safety programs in consistent with national standards for; project, personnel and assets	25%
Environmental Dimension			
Sub- Dimension		Indicator	score
CO_2 emitted	A47	Total CO_2 emitted annually	

	A48	Cost of CO_2 credit foregone in place of fossil fuel use	
Ecosystem integration and land use	A49	Minimization of land interference by the area required for project construction	
	A50	Meets protection and conservation requirements to curb; soil erosion, protect river	
	A51	Support from community of planned environmental strategies	
Impact of construction on aquatic and terrestrial environment	A52	Minimization of disruptions of existing features (roads, river course, displacement of people	
	A53	Minimization of impact to specific values such as threated species and introduction of pest species	
Waste generation and resource conservation	A54	Release of toxics into the river	
	A55	Water resource monitoring and management plan for conservation strategies	10%
Market Analysis Dimension			
Sub-Dimension	Indicator		score
Competitive advantage over other technologies	A56	Cost of project electricity compared to grid electricity, PV home system and biogas powered home	
	A57	Availability of a cheaper electricity generating technology	
	A58	Cost spent by a household on lighting compared to that spent by household using kerosene for lighting	
Transformation of the energy sector	A59	Enhanced conservation of other energy resources; biomass	
	A60	Enhanced developments in the community in comparison to a village without electricity access	5%

3.3 Scoring and weighting

The rating system used in this research was an adoption of the IHA sustainability score rating. Scoring is necessary to rate both new and existing hydropower energy systems to support sustainability score against sustainability indicators (International Hydropower Association, 2006).

Table 12 below shows the scoring and rating scheme for the sustainability indicators that was used in this project.

Table 12: Score and weighting

Score	performance	description
5	Strong	At or very near international practice standards Meets or exceeds objectives and measurable targets
4	very good	High standard performance Meets most objectives and measurable targets including all critical ones
3	satisfactory	Essentially meets requirements of sustainable guidelines Some non-critical gaps in meeting objectives and measurable targets
2	Less than satisfactory	Gaps in meeting requirements of sustainability guidelines Gaps in meeting objectives and measurable targets
1	poor	Poor performance Major gaps in meeting objectives and measurable targets
0	Very poor	Very poor performance, failure to address fundamental issues Fails to meet objectives and measurable targets

(International Hydropower Association, 2006)

All indicators were of equal weight and were ranked according to their descriptive performance. For an entity that was not applicable or has no negative effect/impact in the sense that it was compatible to the project, then it scored the full mark (5). According to IHA assessed hydropower plants are regarded as sustainable if they score 3 or more.

The assessment was carried out by evaluating each sustainability indicator and assigning it a score. The scoring was done by the community members as well as hydropower experts and the results compared so as to minimize level of biasness. The community assessment was through interviews in regard to their view and benefits from the energy system. The same sustainability indicators were then applied to a PV solar home system. The scores were computed and the results compared to those of the hydropower projects.

The rating of sustainability dimensions was based on a priority focus on a rural project setting.

Both economic and social dimensions were highly rated at 30% since they are very critical for community based development projects. The projects were expected to be economically viable and to benefit the community economically while at the same time they should be acceptable.

The environmental dimension was not very critical to renewable based energy systems especially MHP which are considered to be ecofriendly. Hence, the low rating of 10% since the dimension did not have advance impacts on the environment.

The technical dimension had a high rate of 25% since it was very essential for monitoring performance of the project plant. Many projects have failed due to poor technical assessment especially on maintenance. For the project to run throughout its forecasted lifespan, technical monitoring was of essence. The market analysis dimension was a platform to check the performance of the project against competitive supplementary energy sources. It is important to evaluate how the technology is performing for investors as well as stakeholders. However, the dimension did not have crucial impact to the project directly hence the low rating of 5%.

CHAPTER FOUR

4.0 RESULTS AND DATA ANALYSIS

This chapter provides an analysis of the sites visited during the study and the findings of the research. A brief description of each site is provided to review the status of the plant with respect to sustainability point of view. The MHP plants that were evaluated in this research are shown in the table below.

Table 13: Study sites

No.	Project Name	Location	Ownership	capacity (kW)	Household served	Year commissioned
1	Tungu-Kabiri	Meru- South	Community	18	Business center	2000*
2	Ngerechi	Muranga	Community	5	30	2007
3	Ndiara C	Muranga	Community	11	70	2009
4	Kiangima	Kirinyaga	Community	20	24	2006
5	Kigwathi	Nyeri	Community	2.5	10	2009
6	Somorio	Bomet		1.5	15	2007
7	Diguna	Nairobi	missionary	14	Workshop	
8	Kaproret	Kericho	Finlay tea	120	Tea factory	1952

All the MHP plants were fully operational apart from Tungu-Kabiri that developed a mechanical breakdown of the generator in 2007 and has never been repaired since then. The MHP plants fall under the class of medium head since they have a head of above 10M but less than 50M. Such medium head hydropower schemes have their efficiency ranging between 60% to 80% (British Hydropower Association, 2005).

4.1 MHP projects information and status

Figure 12: Kaproret MHP plant

All the existing community MHP projects were mainly used for lighting and charging low voltage appliances like; mobile phones, torched, electric lamps and computers. The projects were wholly managed and maintained by the community. Members of the projects regarded to them as a success since they no longer used kerosene lamps at night amongst other indirect benefits rendered by the projects. The findings and highlights of each project are discussed below in consideration to:

- Good design,
- Purpose,
- Technology transfer,
- Repairs and maintenance,
- Future projections for the project,

Tungu-Kabiri MHP project

This is an 18 kW project in Meru- South district. It was funded by UNIDO and Practical action and commissioned as a pilot project for rural electrification in 2000. The project was to be implemented in two phases; first phase was to supply electricity to a business center and provide a water pumping scheme to supply water to the community. This project enabled opening of various businesses such as battery charging, welding, hair dressing, cinema room, and water kiosk. This phase was very successful and the project greatly influenced technology transfer of MHP technology within the country especially in Kirinyaga County.

The first stage was completed and operational in 2000 up to 2007 when the generator broke down due to mechanical problem and has never been repaired since then. The second phase was to connect the micro grid to the community household. However, this phase was never implemented and the community is still hopeful that the funding organization will still follow up with its implementation.

Ngerechi Self-help MHP project

This project was commissioned in 2006 and was wholly funded by the project members. It is a 5 kW MHP project in Muranga serving 30 household, with a monthly flat rate tariff of 200 KSH. Originally the project was planned to serve 60 households but most of the members could not afford the transmission cost to their homes. The electricity generated was wholly used for lighting; members are limited to using energy saving bulbs of between 5W to 10W. The project is of great benefit to the community and the members regard to it as a successful story. However the design of the intake and the penstock was not good leading to head loss hence low power output.

Due to the significance of the project and the good maintenance, Safaricom Kenya LTD agreed to help upgrade the project by installing a 10kW MHP project for the community. This new project was under construction with modern design and was to be commissioned later this year.

With the upgraded project, the community members will be able to open some businesses and also use the electricity to boost agriculture and fishing by storing the produce.

Ndiara MHP project

This community project was commissioned in 2009 with an installed capacity of 10kW and generates 11 kVA. It connected to 70 household and was wholly funded by the project members. The monthly billing was a flat rate per household of 100 KSH. The original number of members was 150 but most could not afford the transmission cost while others left the project due to conflicts and arrival of the national grid in the region. The main conflicts arose from power outages in some sections of the community due to lack of enough power to serve all the project members. Secondly, there was evident of poor maintenance of the machines leading to frequent breakdown of the systems.

Kiangima MHP project

This is a 20 kW MHP project in Kirinyaga county that was commissioned in 2006 along river Rutui with a head of 11M. The project was originally started by 150 members, however only 24 members are now connected to the micro grid which was a third of the total grid design. The connected members used the electricity for lighting, ironing as well as shredding animal feeds and pay a monthly flat rate bill of 200 KSH. The rest of the members will get connected once they cater for their transmission costs.

The project was a success with good design and well maintained by the active members. This project has attracted transfer of the technology to the nearby village in Kiangurwe where construction of a 20 kW MHP project was under construction and expected to be operational later this year.

Kigwathi PHP project

This project was commissioned in 2009 with an installed capacity of 2.5 kW and connected to 10 household. There were no monthly billing to the members but they are expected to contribute for maintenance and repairs in case of a breakdown. The original number of project members was 27; most of them could not afford the transmission cost to their homes even after contributing for the capital cost of the project. The electricity generated was used for lighting and charging low voltage appliances such as mobile phones, radios and TV sets. The plant was well maintained and the members were very satisfied with the project. However, the intake and the penstock were poorly designed.

Somorio (Iria Maina) PHP project

This is a 1.5 kW project along river Itare in Bomet County funded by UNIDO and commissioned in 2007. The micro grid was connected to 15 household with a monthly flat rate billing of 200 KSH. The electricity generated was mainly for lighting and charging low voltage appliances. The project was successful due to the commitment of the members and the proper maintenance. The high potential of the resource (river Itare) and the significance of this project have attracted the funding organization to upgrade the project by installing a 200 kW plant. The new plant was almost completed and was expected to be commissioned later in the year. In addition to lighting, the new plant will provide a water pumping scheme and also sell the extra generated electricity to the national grid and enable development of the community.

Private MHP projects

Diguna MHP project

This is a 14 kW MHP missionary project in Ongata Rongai – Nairobi County. The project supplied electricity to the technical school for the orphans. It was commissioned in 1962 and the systems upgraded in 2013. Electricity generated was used in the kitchen, offices and the workshops to run the machines as well as pumping water to the institution. The technical workshop machinery consumed a lot of electricity and the MHP enabled the institute to save on electricity cost from the national grid. The electricity Generated by the MHP was not sufficient for the institute consumption; some of the electricity was supplied by the national grid. The projects future projection is to upgrade the MHP plant for more electricity generation to cater for all the institute's energy demands.

Most of missionary hydropower projects had this technology transfer from this project due to its significance to the institute. The project was well maintained. However, the site was prone to floods during the rain seasons which hinder electricity generation.

Kaproret MHP project

This is a private 120 kW projected owned by Finlay, a tea processing and packaging company. The plant was commissioned in 1952 and has two turbine of 60 kW each. It is an old system utilizing a flywheel for energy storage. The electricity generated was used for tea processing in the companies factory. The plant was well maintained with planned maintenance carried out weekly, every Monday when tea processing was not done in the factory.

This project showed significance cost cutting on grid electricity consumption and the company installed two more hydropower plants of 800 kW and 1100 kW in the region. The three hydropower plants supplied half of the factories electricity demand saving the company approximately 40,000 USD on monthly basis (based on current industrial tariff of 0.15 USD/kWh). The company future projection is to eliminate use of wood fuel in steam engines by upgrading the MHP to 240 kW and to install more hydropower plants since the region has high potential.

4.2 Financial Data analysis

Micro Hydropower (MHP) projects

Most of the community MHP projects were funded my non-governmental organizations (NGOs) that financed the installation of the project except for transmission. Hence, the project management had no financial document of the installation cost since the project was handed to the members after implementation. For the self-funded projects, the members raised the capital by themselves without and help from the government or the NGOs. Each member contributed an equal share, however the transmission costs to their houses was upon the individuals.

Hydropower plants have long lifespan and can operate for 50 years without substantial replacement cost (IRENA, 2015) For the purpose of this study, the projects lifespan was computed as 30 years and a maximum discharge of 70%. The formula below was adapted for calculation of the projects LCOE.

$$\boldsymbol{LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}}$$ **Equation 3**

(IRENA, 2012)

Where:

LCOE = Average lifetime levelized cost of electricity generation

I_t = Investment expenditure in the year t

M_t = Operations and maintenance costs in the year t

F_t = Fuel expenditures in the year t

E_t = Electricity generated in the year t

r = Discount rates

n = Economic life of the system

The MHP project had no fuel consumption expenses; hence Ft was not taken into account in this research. The results of financial and LCOE analysis of the community MHP projects are presented on table 14 below.

Table 14: Financial analysis sheet

MHP project name	Kiangima	Ndiara C	Ngerechi	Kigwathi	Somorio
Installed capacity	20kW	10kW	5kW	2.5kW	1.5kW
Investment cost	4556000.00	3628000.00	2568000.00	765000.00	836000.00
Payback period (years)	19.9	20.4	28.8	16.0	15.3
Cost/Watt (KSH/W)	227.80	392.80	513.60	306.00	557.33
Monthly O&M costs	1440.00	1500.00	1400.00	1000.00	2400.00
LCOE (KSH/kWh)	2.99	10.56	13.51	7.36	20.25
(USD/kWh)	**0.03**	**0.11**	**0.14**	**0.08**	**0.21**

From the cost analysis presented on table 14, the projects were found to have a low LCOE with an average cost of 0.12 USD/kWh. The LCOE values were within the range provided by IRENA of 0.02USD/kWh to 0.1 USD/kWh for small plants and about 0.27 USD/kWh for pico-hydro systems in developing countries (IRENA, 2012). The cost per watt range for SHP is 3.4 USD/W to 10 USD/W (IRENA, 2015).

The community MHP projects had very low LCOE because the cost greatly depend on the components cost, labor and materials. Some components like land were donated by the community free of charge. The project members also provided labor for the project set up like digging the channels and construction of powerhouse and the tunnels; this contributed to sweat equity which is not paid in the country. Project members also provided posts for the transmission lines. The O&M costs were also very low (0.95% of initial cost) as compared to value of 1-2% of investment which was used to compute costs by the IRENA report.

All the projects had a benefit cost ratio of above one (with an average of 1.3) which satisfies the financial project requirement to have a ratio of one or above. However the payback periods of the projects were very long (15 years to 28 years). This was attributed to the projects low utilization factor of the community projects and the lack of external source of income generated from the electricity use.

Solar Home System (SHS)

The SHS study was on a 15W polycrystalline solar PV homestead with 90 AH battery and supplying power to four LED bulbs of 3W each. Other appliances included; a radio and mobile charging. The LCOE calculation was as shown below (table 15); the lifespan of the system was assumed to be 20 years.

Table 15: Solar Home System cost analysis

SHS 15W	cost(KSH)
Initial cost	13550
O&M cost	360
Cost/W	903.33
cost/kWh	64.45 (0.69 USD/kWh)
Payback Period	9 years

From the above findings, the cost of the solar PV electricity was a little higher than the cost dictated by WBG where the cost per kilowatts hour for solar PV of less than 25W range from 0.34-0.52 USD/kWh (World Bank Group, 2006). When compared to the LCOE of MHP (0.12 USD/kWh), solar PV home system was more expensive. However, SHS had a lower payback period of 9 years compared to MHP projects whose range was 15-28 years. The high cost of SHS was attributed to the storage system where the battery costs more than half of the initial investment and had to be replaced in every five years.

Figure 13: Portable solar PV panel

Solar PV was however very economical for Arid and semi-Arid regions of the country where the potential is high and the national grid was not accessible. The technology was attractive due to availability of wide range of sizes and application. Communities without appropriate rooftops for the installation could use portable solar PV panels which were capable of charging lamps and mobile phones. Such communities can be energy dependent, they use wood fuel for cooking and heating and they do without use of kerosene lamps.

4.3 Co_2 analysis

In this section, CO_2 reduction was analyzed as the amount foregone by eliminating use of kerosene wick lamp. Most of the project members used Light Emitting Diode (LED) bulbs of very low voltage (5v- 8v) for lighting. They no longer used kerosene lamps hence saving on household expenditure where a household in Africa is estimated to spend 10-25% of monthly budget on kerosene (n.d, 2013).

A liter of kerosene used in a kerosene wick lamp produces 2.56 kg of CO_2 (WorldPress, 2016). In this research, before the installation of the MHP plant a homestead used an average of 5 liters of kerosene in a month which accounts for 12.8 $KgCO_2$/Month. Therefore a plant like Ngerechi which had 30 members saved 4.608tCO_2/year. The negative effects of kerosene lamps were several ranging from; CO_2 emission, black carbon emission as well as health issues such as lung diseases. MHP plants had completely eliminated use of the kerosene lamps by providing clean light to the community.

4.4 MHP Sustainability score and ranking

The projects were ranked based on their score against each indicator of sustainable development. Scoring was based on the interviews carried out, group discussion with members and observation of the projects' status. The collected data was then compiled using excel sheet for ease of computation and ranking the projects sustainability level. The results are presented on table 16 below.

It is evident that some projects were more sustainable compared to others; all the MHP projects were expected to operate for their entire lifespan (50 years for MHP and 20 years for SHS). Private/industrial plants scored higher compared to community projects. Most of the MHP projects were more sustainable in comparison to SHS. The results, findings and issues on sustainability are discussed in details in the next chapter.

Table 16: Sustainability evaluation scores

No.	Indicator	Hydro project evaluation Scores								
		Tungu-Kabiri	Ngerechi	Ndiara	Kiangima	Kigwathi	Somorio	Diguna	Kaproret	SHS
	Economic dimension									
1	Availability of the resource	4	4	4	4	3	5	4	4	3
3	Cost of generated electricity	4	4	4	4	4	4	4	4	3
4	Ability to serve projected lifespan	2	3	2	3	3	4	4	4	3
5	Benefits to cost ration	3	4	3	4	4	4	4	4	3
6	Additional benefits (microeconomic environment)	4	1	1	2	2	1	3	2	1
7	Policies and regulatory approval	3	3	3	3	3	3	3	3	3
	Percentage financial score (30%)	**20**	**19**	**17**	**20**	**19**	**21**	**22**	**21**	**16**
	social dimension									
8	Affordability	4	4	4	4	5	4	4	4	3
9	Accessibility	2	3	2	2	3	3	4	4	4
10	Social impact; acceptability	4	5	2	4	5	4	4	3	4
11	Poverty reduction; enhancement of quality of life	4	3	3	3	3	3	3	3	3
12	Energy use and user conservation	2	2	2	2	2	2	3	4	2
	Percentage social score (30%)	**19.2**	**20.4**	**15.6**	**18**	**21.6**	**19.2**	**21.6**	**21.6**	**19.2**
	technical dimension									
13	Demonstrated technical success	3	3	3	4	3	4	4	4	4
14	Capacity utilization	4	2	2	3	2	2	4	4	3
15	Operation and performance	1	4	2	3	3	4	3	4	4
16	Technology transfer; capacity building	3	2	1	1	1	2	2	2	1
17	Safety issues	2	2	2	2	2	2	3	3	3
	Percentage technical score (25%)	**13**	**13**	**10**	**13**	**11**	**14**	**16**	**17**	**15**
	environmental dimension									
18	Intensity of C02 emitted	5	5	5	5	5	5	5	5	5
19	ecosystem integration and land use requirements	4	5	5	4	4	4	4	4	4
20	Impact of construction on aquatic and terrestrial environment	4	4	4	4	4	4	4	4	4
21	Waste generation	5	5	5	5	5	5	5	5	5
	Percentage environmental score (10%)	**9**	**9.5**	**9.5**	**9**	**9**	**9**	**9**	**9**	**9**
	market analysis dimension									
22	Comparison with other market energy prices	4	4	4	4	4	4	4	4	3
23	Transformation of community and energy sector	2	1	1	1	1	1	2	2	1
	Percentage market score (5%)	**3**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	**3**	**3**	**2**
	percentage score	64.2	64.4	54.6	62.5	63.1	65.7	71.6	71.6	60.7
	Aggregate score	3.21	3.22	2.73	3.13	3.16	3.29	3.58	3.58	3.04
	sustainability ranking	5	4	9	7	6	3	1	1	8

CHAPTER FIVE

5.0 DISCUSSION

This chapter discusses the sustainability of the case study MHP projects as well as the SHS. It reveals their strengths and the missing gaps in these projects and shows how the Kenyan MHP sustainability findings collate to previous research findings.

5.1 Sustainability level of MHP in Kenya


Figure 14: Somorio project turbines

Rural electrification utilizing MHP for micro grids is a recent technology in Kenya which started in 2006 after policies to enable electricity generation of private/communal projects. The community MHP projects were of significance to the community due to the benefits generated from the projects as highlighted in this chapter. Most of these plants were materials were locally available owing major costs to turbine and generator set as well as transmission to the households. This rendered the technology economically viable. However, on sustainability development concept, most of the plants lacked resilience infrastructure to function appropriately for the entire lifespan.

From the sustainability evaluation and ranking table (table 16), the MHP projects score ranged between 2.73 to 3.58 with an average score of 3.23. This indicated that most of the plants in the country were within sustainable level since they scored above 3 (satisfactory, meets essential sustainability guidelines) based on IHA ranking. The level was however lower than sustainability level of Nepal MHP projects which were ranked at 3.61 according to research done in 2011 by Dwarika Adhikari. This was attributed to multipurpose use of Nepal hydropower projects as well as higher technology transfer in the country (Adhikari, 2011).

From the study, some projects like Somorio and Ngerechi had a higher sustainability score mainly due to better scheme management as well as social harmony. Only Ndiara project scored less than three, this was mainly because it was faced with communal conflict that arise due to poor maintenance causing frequent breakdown of the turbine. Secondly the number of household served by the MHP plant was high making power sharing decision by management difficult.

The social dimension was faced with great sustainability concern. Most of the initial members could not access the electricity due to lack of transmission fee. In most plants the transmission and distribution had not covered two thirds of the design installed capacity rendering the generated electricity underutilized. Most of these members contributed for the capital cost and provided labor during construction but could not use the electricity.

All the projects exhibited no major concern with the environmental analysis. This was mainly because SHP plants have no major adverse effect to the environment (Department for International Development, 2000). There were no negative feedbacks with relation to land use, water use or any waste generated by the plants. The members were well educated on conserving the environment. They planted grass along the water channels and trees within their power plants.

The market dimension scored very poorly on sustainability level since the projects' electricity generated was solely for lighting. The projects had helped to minimize wood fuel consumption which was mainly used for cooking, heating and lighting in rural areas. Study conducted in India to assess social-economic impact of MHP for lighting in villages revealed that the greenery of the village increased by 30% compared to previous years (Anup, Ian, Jin, & Sang-Eun, 2011).

There were no hybrid systems installed to operate in hand with the MHP projects. Arrival of grid electricity in some regions such as Ngrerechi and Kigwathi did not cause much change or members leaving the projects. This was because the monthly billing of the project electricity is very cheap compared to the grid electricity. For grid connection household consuming electricity for lighting and charging low voltage appliances like mobile phones paid an average of 380 KSH per month. From which there was a fixed charge of 150 KSH and 20.57 KSH/kWh (Regulus Limited, 2016).

The MHP were majorly for supplying electricity for lighting and charging low voltage appliances such as mobile phones, torches, TV sets and Radios. Their sustainability greatly depended on the level of maintenance and communal harmony. Most of such projects for example; Thima, Mungetha and Thigaa projects failed due to conflicts, theft and mechanical breakdown due to poor maintenance.

Private/industrial plants scored higher on sustainability rank. This was because they were properly maintained and the driving force to cost cut on electricity bill suppressed the communities drive to provide electricity for lighting. Secondly they had appropriate system design and sizing of; intake, penstock and machinery enabling proper utilization of hydro resource. The companies also have proper documentation and accountability of the project unlike the community projects.

MHP projects were found to be more sustainable compared to solar PV home system. This was mainly on the reliability of the electricity generated and the cost of generation. Electricity from MHP was available throughout the year at affordable cost whereas for a solar PV home, the battery had to be replaced after every five years. The solar PV system provided dim light and could not charge some appliances during cloudy days of the year. Lack of proper guidance on design and sizing of the solar PV system posed a great challenge to users; the system functioned very well only during the sunny seasons. This perception has made many people in resource potential areas to quit the technology on allegations of failure.

On the other hand, Solar PV home system had fewer losses since it did not require transmission. The system was also independent of the members hence no conflicts in the community. The technology was economic for arid and semi-arid areas where the population is sparse and installing a grid would be expensive. The user was very satisfied with the system; the only complains reported were poor performance on the cloudy day and the short lifespan of the battery.

The sustainability level of the MHP projects in Kenya can be greatly improved by various measures. First there is need for carrying out a conclusive feasibility study before implementation of the project. The study revealed that most of the projects did not have a conclusive financial budget covering on transmission of generated electricity. For this reason, only few members could afford the transmission cost to their homes when the project was completed.

Secondly projects should adopt appropriate designs to avoid losses such as transmission losses and head loss. Most projects had poor transmission wire and the posts were not treated requiring them to change them within two years of operation while on the other hand treated posts can last more than 15 years. Third, the management needs to open up some small business opportunities to improve on multipurpose use of generated electricity. This will generate income for the projects as well as improve the plants load factor.

5.2 Significance of MHP to rural communities

The benefits generated by MHP projects to the community that made them attractive for rural electrification are highlighted below.

i. Affordable access to electricity; the projects had a low LCOE and a high benefit to cost ratio as shown in the previous chapter’s the financial analysis. The affordability of the electricity was evident by the monthly billing as some members paid about 2USD while some plants like Kigwathi did not charge any monthly fee to members. Before the implementation of the project, most members used kerosene lambs spending about 5litres a month at a total cost of about 4.5 USD.

ii. Security; members of the community felt safe when they light their homesteads at night, most of them especially in central province reported a decrease in domestic theft cases during the night.

iii. Health benefits; use of kerosene lamps had severe damage to lungs and some children complained of eye infections when using the lamps for their studies. Accessibility to electricity has eliminated this vice by providing clean energy to homesteads.

iv. Educational benefit; students were able to comfortably work on their homework in the evening in the comfort of clean light.

v. Comfort and improved standard of living; members had bought TV sets and could charge their appliances in the comfort of their homes. They were able to watch news and were aware of what is happening and new developments.

vi. Harmony in the society; the plants have strengthened the members by uniting them to contribute to the wellbeing of the project. They often met to discuss project issues. When there was a breakdown they contributed for maintenance and repairs. The members also offered security to their plant and guarded the transmission lines.

vii. Green development mechanism; some plants like Ngerechi and Somorio had attracted NGOs that offered to fund for installation of bigger units due to the significance of the project in the region and availability of the resource. The new plants will help in development of the region since they are business/industry focused.

viii. Business and trade; some projects like Kigwathi supplied electricity to the tea selling center. They were able to sell their tea late in the evening and supplied electricity to the center office.

ix. Benefit to farming; projects with bigger capacities such as Kiangima enabled the members to use the electricity for shredding and milling animal feedstock. The members did not have to go to the town center and pay for those services.

Most of the benefits delivered by the MHP to the community were indirect benefits. The projects have also help women and girls since they could comfortably cook late in the evening and wake up early in the morning to prepare breakfast comfortably. The communities were energy dependent and had owned the project since they had greatly contributed to project's wellbeing. Members were very positive to the success of the project and they felt honored to be associated with the project.

5.3 Challenges facing community MHP projects

Figure 15: Kigwathi MHP plant intake

Despite the significance of these projects to the community, there were various challenges that face them thus threatening their sustainability. According to Practical Action report of 2011, most challenges faced by micro hydropower are part of a large picture on policies and budgetary allocations. The report lists the main challenges as; lack of clear policies on renewables, supportive investment sector, and absence of lost-cost and long-term financing models for sustainability of the plants (Practical Action, 2011).

The major challenges facing the projects were portrayed as listed below;

1) Financial challenge

Financing the project by the members posed a great challenge leading to poor design and use of low quality materials. Most of the plants had poor transmission cable with high resistance leading to greater losses of generated electricity. Most of the designing work was done by the members for example in Ngerechi, Ndiara and KIgwathi since they could not afford to hire experts for help. Plant like Ngerechi had to change the penstock size after installation on realizing it had huge head losses. Cost of good design was a great threat to sustainability of the plants. Some plant like Kiangurwe in Kirinyaga could not function after installation due to sizing error of the turbine.

Funding for repairs by the community members was also a great challenge especially after breakdown of major components. This was evident by Tungu-Kabiri where the generator broke down in 2007 and the members were unable to raise funds for repair to date. Other plants faced by the same problem leading to abandonment of the project, for example Thigaa, Thima and Mungetha MHP projects in Kirinyaga County. Transmission costs also posed a great challenge. Most of the plants transmitted the electricity over a long distance (more than a kilometer) without transformers resulting to increased losses.

Investment fail was another great challenge to the community projects. However, this is mainly contributed by lack of proper feasibility study and poor design and sizing. This was evident in Kiangurwe plant which installed a 30kW turbine but did not generate electricity due to low flow rate that was available. The members were advised to install a smaller turbine of 20kW and redesign the penstock. The project commissioning is expected later this year.

2) Managerial Challenges

All the plants lacked documentation of the projects'; finances, operation, monitoring and maintenance records. There were no laid down long term plans for the projects except for those that NGOs have intervened to upgrade the project. The decision makers of the project had not set up commerce/industries to make use of generated electricity during the day leading to low utilization of the resource available.

3) Social Challenges

These are conflicts that arise among the project members. Most of such conflicts were reported where some members fail to pay for the consumed electricity especially in Ndiara project. Such members were forced to leave the project and the transmission to their homestead is disconnected. Secondly, when the electricity generated is not enough for all the members, rationing in some sections create conflicts as most of the members lack knowledge on operation of the plant. Some members also complained of dim light especially in plants that have large number of household connected.

4) Technical challenges

The main technical challenge was lack of proper guidance on appropriate design for resilient plants. Most of the plants suffered great head losses and transmission losses due to the poor material selection. Secondly all the community projects lacked planned and preventive maintenance schedules. They mainly concentrated on routine maintenance; clearing the track rash and corrective maintenance in case there was a breakdown of components. This posed a great challenge since the communities had no funds set aside for major repairs which were the main cause of project abandonment.

Third, projects lack transformers and mechanisms for regulating generated electricity resulting to poor methods like use of electric resistor coils as energy dumpers. This posed a safety hazard for the power house as well as great loss of generated energy.

The projects were mainly for providing lighting creating a low utilization factor of the plant; this can be improved by providing other services such as water pumping.

5.4 Conclusion

This study found that Micro hydropower provides sustainable electricity for rural communities that are far from the national grid. This technology is currently very attractive for reliable and affordable electricity where the resource is available. It is a cost effective technology with the LCOE as low as 0.12 USD/kW since most components were locally available and sweat equity was provided by the community. Electricity generated by the plants had numerous benefits to the community such as; improved standards of living, cohesion among community members, improved security in the society, education benefits where children had increased hours for their studies and boost in trade and agriculture. Women had more time for their household duties and could start income generating businesses such as hair dressing.

The projects have reduced CO_2 emission by eliminating use of kerosene lamps. A household that was initially using five litres of kerosene in a month was found to save 12.8 $KgCO_2$/Month. The ability of the MHP project to supply clean energy had attracted private organizations such as Safaricom Kenya limited that offered to fund for upgrade of projects like Ngerechi project.

Kenyan MHP projects were revealed to be within sustainable level (3.16 score) and offered affordable electricity access to remote communities making them energy dependence. However, there was need to improve their sustainability by improvement of their design, proper maintenance and repairs and training of operators. With proper maintenance these plants can sustainably serve the communities for 50 years without substantial replacement costs (IRENA, 2015).

The main challenge facing the MHP projects in Kenya was lack of local capacity in designing and developing the plants. Feasibility studies were not carried out by specialized personnel to produce detailed design and costing of the system which lead to failure of most projects after implementation.

5.5 Recommendations

There is need for government involvement in the implementation of these community based MHP project, not only in policy making but also guidance in implementation and providing funds, subsidies and grants. Most of the plants lack financial support ending up with poor design and transmission systems.

Technical challenges such as low load factor should be addressed by starting up commercial/industries to utilize the generated electricity during the day such as; computer schools, water pumping schemes or workshops. These industries will enable the projects to generate income.

Capacity building in form of training operators and management team should be affected for smooth operation of the plant components, proper documentation of plant records and long-term planning of the project.

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APPENDIX

THESIS QUSTIONNAIRE:

SUSTAINABILITY ASSESSMENT OF MICRO HYDROPOWER IN KENYA

(USER QUESTIONNAIRE)

Micro Hydropower Project Name:…………………………………Location:…..……………..

This questionnaire consists of open ended questions; give your view and a brief explanation. Kindly assign a score for each question according to score and weighting indicated below:

5= Excellent	4= Very good	3= satisfactory
2= less than satisfactory	1= poor	0=very poor

Number of people in your homestead:	Number of bulbs:	
Monthly electricity consumption	Other Appliances:	
Monthly electricity cost:		
What are your electricity uses:		
Is the electricity reliable (how often are outages experienced):		
In what ways do you save/conserve electricity:		
How has your quality of life improved since you gained access to electricity:		
How has electricity improved market and trade in your community:		
Is there any business this project has enabled you to run/open: how much does it generate per month		
What tangible benefits has electricity generation added to your family other than lighting		
Are you satisfied with the management:		
Can the community run the project without outside intervention:		
What is your involvement in the project: do you attend meeting		
Has you land or drinking water been affected effects due to the project construction:		
Are there any conflicts within this project:		

What other technology of electricity generation are available (are they cheaper):	
Which other energy resource do you use; is it cheaper	
Are there people willing to get connected but cannot afford to pay for the electricity	
In your own view, how has health improved due to electricity access:	
In your own view, how has education improved due to electricity access:	
Has the project helped girls/women in daily life:	
How much do you spend on electricity (for those using electricity for lighting alone):	
Before the project, how much kerosene (litres) did you use in a month, how much was its cost:	
How has your farming been improved by the project:	
Has the project affected your cultural practises in any way:	
In what way are you involved in water management and river conservation:	
Did the project require any land to be volunteered or bought from the community, how much:	
Has the project construction caused any inconveniences; load block ,river course change or conflicts:	
Has the project affected the behaviour of other organisms, such as pests (mosquitos), birds, insects and fish:	

NAME:

THESIS QUESTIONNAIRE:

SUSTAINABILITY ASSESSMENT OF MICRO HYDROPOWER IN KENYA

(MANAGEMENT QUESTIONNAIRE)

Micro Hydropower Project Name:…………………………………Location:…………………..

This questionnaire consists of open ended questions; give your view and a brief explanation. Kindly assign a score for each question according to score and weighting indicated below

5= Excellent	4= Very good	3= satisfactory
2= less than satisfactory	1= poor	0=very poor

No. of connected households:		Capital cost:	
Installed capacity:		Monthly O&M costs:	
Project lifespan:		Cost of generated electricity:	
Head		Length of transmission lines:	
Penstock diameter; length		Number of people connected;	
Turbine type; size		Total number of people in the community:	
Generator type; size		Total project area (land)	
Hours of operation in a day:		Number power outages in a month:	
Services provided by the project other than electricity generation:			
Is the electricity generated reliable, how often do breakdown occur			
How often is the planned maintenance carried out, how long is the shutdown			
Off-peak; adjustment and power usage			
What integrations has the plant offered with other energy generating technologies:			
What are the future expectations/arrangements for the project:			
What are the tangible developments/benefits in the community from the project (roads, school industry or hospital)			
What threats are there from other energy sources			
Is electricity from the project favored compared to other sources; why			
What conservation and energy saving measures are done at the power plant			
What are the major causes of electricity loss			

What regulations are there for this project, are they adhered to:	
What certification is required for this plat by the Kenyan law, do you have the certificates	
How often do authorities from the law visit the plant	
How many jobs has the project created	
Are there planned safety programs for the project , who is in charge of them	
Has the project caused any injuries or damage to the community, how are they compensated	
Is there any village around that has implemented or seeking advice on how to construct a plant like this one	
Has the project helped to minimize over dependent on wood fuel, how	
What measures are in place to conserve the water and the river banks	
What type of waste is generated at the power plant, how is it disposed	
Plant's load curve:	

Name:

Position: