Sustainable Management of Micro Hydropower Systems for Rural Electrification

The Case of Mt. Kenya Water Catchment Area

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Declaration

A Student's Declaration

I confirm that this project report is my own work and has never been submitted before for examination purposes or any other purpose.

AKAKI, Rodgers O., F56/70943/2007

Signature..................................

Date..

B. Supervisors' Declaration

I confirm that the above student carried out the research under my supervision for the entire period of the research project.

Prof. Felix Makau Luti

Signature..................................

Date..

Eng. Odera O. Benard

Signature..................................

Date..

Dedication

I dedicate this research to my family and particularly to my 4-year old son, Joel Akaki, for their understanding of my late evening arrivals at home as I undertook my studies.

Abstract

The critical role that energy plays as an input to socio-economic development and environmental protection is universally acknowledged. It is an important vehicle for income and employment generation and for satisfying basic human needs. The provision of adequate, quality and affordable energy services can play a decisive role in poverty reduction.

Some of the problems that have besieged rural electrification in Kenya include inadequate policies, limited application of appropriate technologies, limited financing and weak institutional frameworks. This study explored the challenges and opportunities associated with the sustainable management of micro hydropower systems by evaluating some of the systems which are in existence in the Mt. Kenya region. Data collection was based on field surveys and key informant interviews, complimented by a review of the existing literature.

The research also assessed the sustainability and affordability of power provided to rural communities through the government sponsored rural electrification programmes vis a vis community based small scale power generation schemes such as micro hydropower systems.

Developing sustainable end uses from the produced power is an essential aspect of community-based micro hydro power development. In the projects surveyed in the Mt. Kenya Region, the plant factor is very low. This is because most consumers only use their lights for 6 hours. Successful implementation of the day use distribution system will improve the plant factor significantly, increase system income, and create revenue generating enterprises.

It is important for the government and other stake holders in the energy sector to gain a better understanding of the strengths and weaknesses of the community-based management model of the micro hydropower systems in order to help enhance the formulation of the required policies for their sustainable development, management and replication.

The policies formulated should emphasize on clearly spelling out the development and management of distributed non-convectional renewable energy such as micro hydros, which otherwise might be marginalized, with preference given to building larger hydropower plants that are techno-economically cheaper per kW installed.

The regulatory framework, by institutions such as the Energy Regulatory Commission (ERC), is also important to ensure that there are policies and regulations governing the development, management, operation and maintenance of the micro hydros in order to guarantee safety and sustainability.

Acknowledgment

I would like to express my gratitude to the following people and organizations, without whose support it would have been difficult to carry out this study successfully.

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I cannot forget to express my appreciation to the my colleagues Agnes, Patrick, Kennedy from the Energy Regulatory Commission, Mr. Benson Okwiri from BAT and Mr. Wachira Kahoro my classmate for being with me during the field surveys. I would particularly like to acknowledge the splendid assistance, and their valuable time and information given to me during my field survey in the Mt. Kenya Region.

The moral support gotten from my family cannot be over-emphasized. Special thanks to my 4-year-old son Joel Akaki for encouraging me to burn the midnight oil to complete this study, if just to avoid his taunts of ‘Daddy, why are you reading like children and you are old?, and does your teacher teach you ‘a b c.........z’ like our teacher Monica?’

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Acronyms and Abbreviations

AfDB	-	African Development Bank
AFREPREN	-	African Energy Policy Research Network
CUMEC		The cumec is a measure of flow rate. One cumec is shorthand for cubic metre per second.
ELC	-	Electronic Load Controller
ERC	-	Energy Regulatory Commission
ESHA	-	European Small Hydropower Association
GEF	-	Global Environment Facility
GNESD	-	Global Network on Energy for Sustainable Development
HDI	-	Human Development Index
IEA	-	International Energy Agency
ITDG – EA	-	Intermediate Technology Development Group – East Africa
KPLC	-	Kenya Power and Lighting Company
kW	-	Kilowatt
kWh	-	Kilowatt-hour
MDG	-	Millennium Development Goals
MHP	-	Micro Hydropower
MoE	-	Ministry of Energy
MW	-	Megawatt
NEMA	-	National Environmental Management Authority
REP	-	Rural Electrification Programme
UNDP	-	United Nations Development Programme
WEC	-	World Energy Council
WCD	-	World Commission on Dams

CHAPTER 1
INTRODUCTION

1.1 Background

About 2 billion people in the world lack access to commercial forms of energy including electricity. Lack of access to electricity affects mostly rural areas of developing countries [32], [9]. Electricity can meet a diversity of human energy needs compared to other forms of energy and access to reliable and affordable electricity in rural areas has the potential to improve the provision of social services such as health and education. Switching to electricity can also help avoid a significant amount of environmental, health burdens associated with traditional fuels. Where infrastructure such as roads, water supply systems and social services are available in rural areas, electrification can result in direct economic benefits [30]. Potential benefits of electricity in rural areas include crop irrigation, agro-processing and preservation of farm produce.

Most developing countries continue to experience limited access to electricity particularly in rural areas. Lack of financial resources from both the utilities and the public sector has resulted in limited investment in system development and maintenance [17].

Although many countries in Africa could rely on abundant water resources, electricity infrastructures are not well developed or evenly distributed, especially in the rural areas. Wood, charcoal, waste and animal dung are the main energy sources for cooking and daily life. This not only causes serious indoor pollution but is also unsustainable due to the pressure put on natural resources and deforestation.

The close interaction between development and energy makes economic development very difficult in the absence of sustainable commercial energy supply. Energy supply plays a key role in the fulfillment of MDGs in Africa. However, widening access to energy services from the national grid through rural electrification programmes is not proven to automatically benefit the poor. On the other hand, small-scale projects, decentralized solutions that encourage productive uses of electricity and community approaches can be successful schemes to tackle poverty.

Small-scale energy projects such as micro hydropower (MHP) are appropriate for decentralized (community-level) management. For example, China's experiences in rural MHP electrification proved that the decentralized development of MHP could be an effective approach for rural energy supply and integrated sustainable social, environmental and economic development [20].

Infrastructures are easy to replicate and the micro-hydropower technology is relatively simple to run. Most remote rural areas of African countries possess abundant MHP resources that enable the replication of successful experiences drawn from pilot projects.

In Kenya, the Sessional Paper No. 4 of 2004 on energy states that there exists hydroelectric potential in the category of small, micro to pico-hydro projects of the magnitude of about 3,000 MW nationally. The Government intends to encourage development of such projects by communities and investors alike through mobilization of resources for undertaking pre-feasibility studies, especially for those commanding high economic merit order ranking [22].

Furthermore the enactment of the Energy Act (2006), has resulted in the establishment of the Rural Electrification Authority whose function under section 67(d) is to promote use of renewable energy sources including but not limited to small hydros, wind, solar, biomass, geothermal, hybrid systems and oil fired components taking into account specific needs of certain areas including the potential for using electricity for irrigation and in support of off-farm income generating activities [5].

Kenya has significant endowment sites suitable for stand alone systems which are suitable to rural energy demand patterns. A number of pilot projects in the area of mini and micro hydro have been implemented to assess the viability of such systems and create the impetus for accelerated exploitation of mini/micro hydro resource [22].

For instance, the Department of Renewable Energy, Ministry of Energy (MoE) and Intermediate Technology Development Group – East Africa (ITDG-EA) with funding from the United Nations Development Programme (UNDP), GEF, Small Grants Programme implemented the Tungu Kabiri Micro Hydro Power Scheme (figure 1). This project is located in Mbuiru Village, Meru South District, about 185 km north of Nairobi. The project generates 18 kW of electricity from a river providing power to about 200 households (about 1000 people), a community which is not connected to the national grid. The community contributed free labour for building the weir, digging the canal, and building the power house, among others. The participation of the community in the construction enables them to both own the project and maintain it, thus ensuring its continuity.

Figure 1. Tungu Kabiri Micro Hydro Power System

Investment cost of micro hydropower system for rural electrification is comparatively high but the advantage of the system is a zero cost on fuel. Therefore, investment is worthwhile when the usage of generated energy is continued for an entire project timeframe. The rural electrification system through micro hydropower systems is sustainable if the management system has these components or major factors;

a. Community involvement in all activities from start to finish such as planning, installation, system maintenance, financial and environmental management of the micro hydropower schemes.

b. Community is capable of maintaining the system by itself in the following ways;

  i. Has technician in village that can maintain the system,

  ii. Member of village committee can understand and be able to do book keeping and manage the fund,

  iii. Strong community capability, members accept and stick to the rule, willing to pay monthly electricity bill, etc.,

c. Electricity helps to increase household incomes such as from weaving, tailoring, welding etc.

d. By using community micro hydro power, the users can reduce other energy costs such as kerosene, candle, etc.

1.2 Research Question

From a management perspective, what are the best technical and institutional mechanisms that will ensure equitable, economically efficient and sustainable micro-hydroelectric power schemes for rural electrification in the Mt. Kenya water catchment area?

1.3 Research Justification

The justification of this research lied in the fact that only about 4% of people in rural Kenya currently have access to grid-based electricity [25]. The cost of electricity is also unaffordable by the rural community. African Energy Policy Research Network, AFREPREN [1] indicates that following the implementation of reforms in Kenya, electricity tariffs were regularly increased. Rural families instead mainly rely on kerosene for lighting, wood fuel and dung for cooking, and diesel-powered systems for tasks such as milling grain. Cooking with traditional biomass causes severe air-pollution and health problems and takes considerable time and effort to collect fuel. Purchasing kerosene may take up about 1/3 of a rural family's income [24].

There are many constraints to rural grid based electrification. Firstly there is the question of cost. The cost of grid connection is influenced by the voltage and proximity of the grid and whether there is a step down transformer already serving the area in question. Capital cost of the distribution system is very high and demand in rural areas is very low. Households can be widely dispersed and often rural consumers will want to use only a few light bulbs and a radio in the evening. The cost-benefit relationship shows that there is little incentive for an electricity producing utility to extend the grid into remote rural areas. More often rural regional centres will be electrified but the network usually stops there or bypasses the remoter villagers as high voltage cables passing overhead. In poorer communities the cost of house wiring, appliance purchase and electricity prices can also be prohibitive.

Although introduction of electricity to a community often stimulates income generating activities and hence a gradual increase in the uptake of electricity use, the conditions for introducing electricity do not normally exist in rural areas. Most commercial and industrial activities are concentrated at the regional centres. In Kenya, the existing generating capacity is unable to cope with demand. Black outs are a common occurrence in many towns, especially as the process of rapid urbanization continues. The utilities often find it difficult to cope with the existing demand, let alone think about catering for an increased demand from rural areas. Positive political will and subsidies or loan schemes for rural electrification can remove some of these obstacles but often neither are forthcoming. It seems, therefore, in many countries of the developing world, little progress will be made if rural communities are to wait for the grid to reach them. In conclusion we can see that an alternative is required. One alternative is the community based micro hydropower systems to provide electricity for local networks.

A micro hydro plant as a decentralized rural energy system can provide technically promising opportunity to address the need of sustainable rural development. It can be integrated with the socio-economic development of rural areas with its linkage in enhancing the agricultural diversification and rural industrialization process. This will accelerate the economic growth in the rural areas through the mobilization of the local resources. In addition, the micro hydro plant as a source of renewable energy system also caters for the global concern regarding the use of environmental friendly energy technology.

1.4 Objectives of the Study

The following were the main objectives of the study;

a. To find out the goals, criteria, and barriers of and to the development and sustainable management of a viable micro hydropower based rural electrification in Mt. Kenya water catchment area, given the current institutional structure.
b. To establish the most cost-effective and efficient institutional delivery mechanism appropriate for operating and managing micro hydropower based rural electrification in Mt. Kenya water catchment area, taking into account accessibility, local resource endowments and institutional capacity.
c. To assess any technical deficiencies in design, installation and operation of the existing MHP plants in Mt. Kenya water catchment area.
d. To give appropriate recommendations.

1.5 Scope of the Study

This study addressed the technical, financial and environmental sustainability of micro hydropower systems found in the Mt. Kenya water catchment area, specifically in the Meru and Kirinyaga districts. This was due to the fact that the two districts are home to the majority of the existing MHP plants and also have more rivers with a great potential for development of micro hydropower systems. The scope of the study was limited to exploring the management of the micro hydropower systems with a view of establishing whether they are economically efficient and sustainable for the support of rural electrification.

1.6 Significance of the Study

The study is meant to assist the government agencies and various private sector stakeholders involved in the energy sector to develop sound policies for the development and sustainable management of micro hydropower systems as a viable alternative energy to rural electrification in Kenya.

The study provided vital information concerning the development and sustainable management of micro hydropower systems for the small scale enterprises, community-based organisations and individual entrepreneurs willing to invest in the energy sector, especially the micro hydropower systems in rural Kenya.

CHAPTER 2
LITERATURE REVIEW

2.1 Energy Poverty Overview

Overcoming energy poverty is one of Africa's great challenges. The majority of Africans currently have no access to modern energy services and technologies. This has wide-ranging social, economic and environmental consequences. Lack of access to electricity means no refrigeration for medicines or food, limits on what type of businesses can be developed, as well as no effective lighting. As a result, children cannot easily study in the evenings. Most Africans, even in urban areas still use firewood, crop residues or charcoal, for cooking, resulting in a high incidence of respiratory diseases because of smoke. Many women and girls have to spend hours collecting firewood and cutting trees, contributing to deforestation [3].

Improving Africa's energy situation is vital if we are to achieve the Millennium Development Goals of halving poverty rates and improving health. On the positive side,

Africa has a vast, largely untapped, potential of both renewable and non-renewable energy sources. In particular, Africa's large hydropower potential appears an attractive option for meeting energy needs.

Yet, to date Africa's experience with hydropower has been mixed, as it has been elsewhere in the world. As Figure 2 shows, many African countries are highly reliant

on hydropower for their electricity supply.

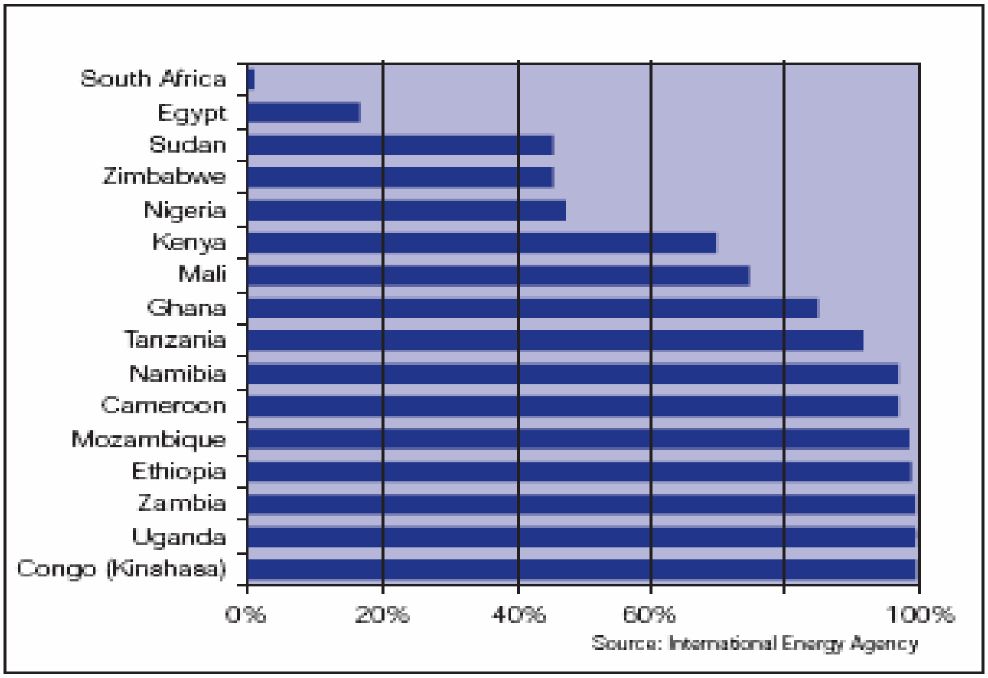


Figure 2: Contribution of Hydropower to Net Electricity Generation (2002) [6]

The challenge is thus to find appropriate and reliable solutions for providing both energy for industrial development and meeting the needs of the majority of poor Africans who live in rural areas. Current projections are not encouraging. Despite a growing number of electrification programmes, the International Energy Agency expects the number of Africans lacking electricity to increase from 535 million now to 586 million by 2030, most of them in rural areas. While electrification rates are expected to increase from 36% currently to 58% by 2030, a large proportion of the population is expected to remain without electricity. At the same time, the number of people relying on traditional biomass for cooking and heating is expected to increase by almost one-third [15].

While hydropower plays an important role in Africa's energy system, its development has brought with it a series of problems. These include inadequate resettlement and a lack of benefit sharing, socioeconomic issues including a failure to address rural energy needs and environmental impacts.

2.2 Energy and Human Development

To better understand the relationship between energy and human development, it is helpful to analyse human development across countries in relation to energy use and access. There have been numerous attempts to develop such analysis. The most notable attempts have focused on illustrating the relationship between human development, as measured by the Human Development Index (HDI), and different aspects of energy use (e.g., per capita consumption, the share of modern energy services in total energy use and the share of the population with access to electricity). These analyses have pointed to a
strong link between energy and overall development.

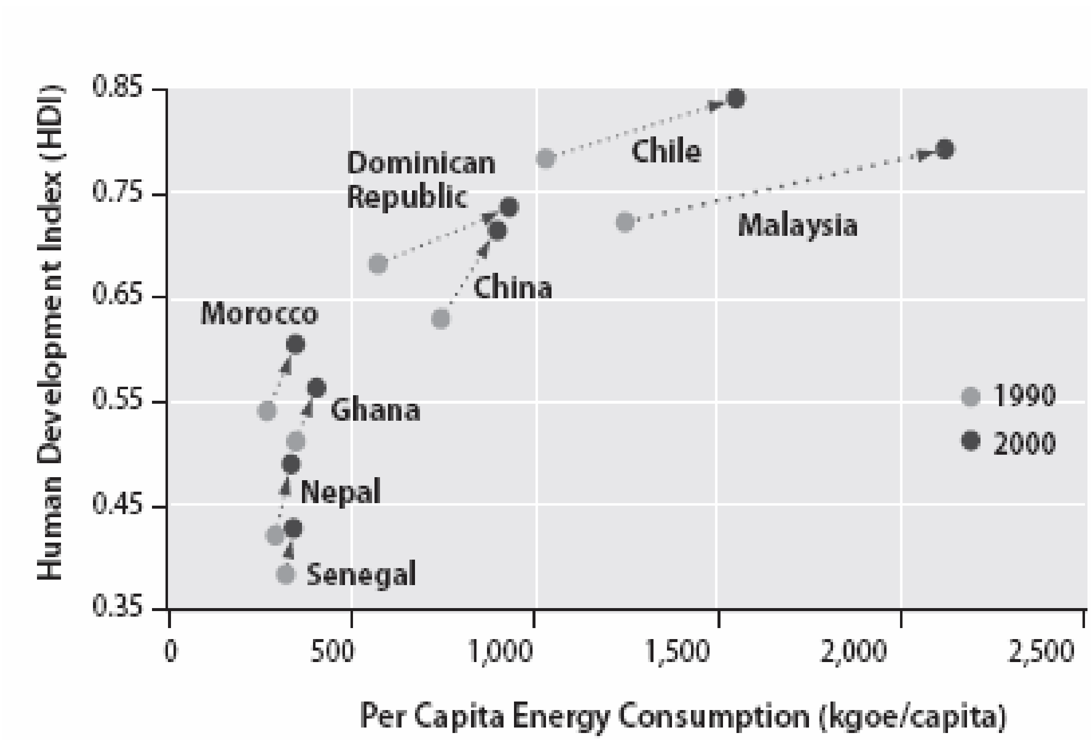


Figure 3. HDI vs Per Capita Electric Energy Consumption [32]

As indicated by the upward sloping trend in figure 3, energy is strongly linked to human development. The figure also shows that as countries develop over time, they do so in tandem with improvements in access to adequate and affordable modern energy services. Moreover, 'no country in modern times has substantially reduced poverty without a massive increase in its use of energy and/or a shift to efficient energy sources' [9]. Of 80 countries for which time-series data on electricity and HDI are available, all but 10 evince the typical development pattern in which trends in average per capita electricity consumption move with the HDI over time. Thus, expanded availability of modern energy services use is strongly associated with human development. [9]

2.3 Flawed Economics and Failure to meet real Energy Needs

Hydropower in Kenya has not necessarily met economic expectations, either in terms of viability or in terms of meeting energy needs. According to the World Commission on Dams (WCD), a considerable number of hydropower projects fall short of their initial economic targets, although only a smaller number can be classified as economically unprofitable. A 1998 African Development Bank review of its experience with six hydroelectric dams found cost overruns of on average 9% and two of the projects failed an economic viability test [3].

Furthermore, while large hydropower projects have produced economic benefits by providing for industrial and urban energy needs, they have done little to improve access to electricity of the majority of the population. Cabora Bassa in Mozambique is a case in point. While nationally, this hydropower project produces more than enough electricity to power the whole of Mozambique, in reality a major part of the electricity is exported to South Africa and Zimbabwe and less than 10% of Mozambicans have access to electricity.

2.4 Micro Hydropower Systems – Definitions

The definition of micro hydropower varies in different countries and can even include systems with a capacity of a few megawatts, as indicated in Table 1 below. One of the many definitions for micro hydropower is: hydro systems up to a rated capacity of approximately 300 kW capacities. The limit is set to 300 kW because this is about the maximum size for most stand alone hydro systems not connected to the grid, and suitable for "run-of-the-river" installations [21].

Table 1: Classification of small, mini, and micro hydro plants in sample Countries [23]

Country	micro (kilowatts)	mini (kilowatts)	small (megawatts)
United States	< 100	100 - 1000	1 – 30
United States	< 100	100 - 1000	-
China	-	< 500	0.5 – 25

USSR	< 100	-	0.1 – 30
France	5 – 5000	-	-
India	< 100	101 - 1000	1 -15
Brazil	< 100	100 - 1000	1 – 30

2.5 Micro Hydropower – Appropriate Solutions for Africa and Kenya

In the last 30 years, China, Nepal, Vietnam and many South American countries have seen the development of a large number of micro and mini hydro projects that have provided electrification for many thousands of households [31, 6]. However, in Africa such projects are few and far between and investments in hydropower have concentrated mainly on large hydro dams. Many utilities and donors prefer large centralised investments because they are considered easier to manage. At the same time, there has been little financial and institutional support to develop smaller scale power projects. Yet distributed power generation through pico, micro, mini and small hydropower could be an attractive option for meeting rural energy needs in many areas in Africa and in Kenya.

Smaller scale hydropower schemes have relatively low capital requirements and through their modular nature, can be sized to meet demand. They also can be integrated with a range of other small scale renewable energy sources such as solar panels or biomass digesters in hybrid systems, designed to suit local resource availability. Micro- and pico hydro in particular offers potential for Kenya, as it can be designed involving local materials and labour, while mini and small hydro schemes require traditional engineering approaches [6]. The modular nature of small hydro technologies allows even the poorest countries of the region to begin a phased energy investment programme that does not strain their national financial resources or draw funds from other basic needs [16].

Many African countries have a considerable small scale hydro potential, although this has generally not been well studied. In Uganda estimates suggest that there is good mini hydro potential on 71 rivers with a total capacity of 220 MW [16]. Currently, only 6 small hydropower plants are in operation, with a capacity of 6.8 MW [13]. Exploiting some of this potential could make a significant contribution to rural electrification in a country where only 3% of the population has access to electricity. Kenya has significant endowment sites suitable for stand alone systems which are suitable to rural energy demand patterns. The current known potential for mini and micro hydro is estimated to be 3000 MW [22]. A number of pilot projects in the area of mini and micro hydro have been implemented to assess the viability of such systems and create the impetus for accelerated exploitation of mini/micro hydro resource [22].

Institutional and capacity barriers to successful small hydropower development are clearly a problem in Kenya but some successful projects exist. One such project is the Tungu-Kabiri micro hydropower scheme (figure 3) in Kenya [14].


Tungu-Kabiri hydropower scheme in Kenya.

Figure 4: Tungu Kabiri Micro Hydropower Scheme

The project is a cheap, sustainable and small-scale technology which also alleviates the environmental problems associated with using wood and dung for cooking, diesel for milling and kerosene for lighting. As a result of the project's success, the Kenyan government is now beginning to embrace and invest in decentralized community management and renewable energy production and to change government policy to facilitate such initiatives.

2.6 The Place of Micro Hydro

Micro hydro, defined as a plant between 5 kW and 100 kW, is perhaps the most mature of the modern small-scale decentralized energy supply technologies used in developing countries. There are thought to be tens of thousands of plants in the 'micro' range operating successfully in China and significant numbers are operated in wide ranging countries such as Nepal, Sri Lanka, Pakistan, Vietnam and Peru. This experience shows that in certain circumstances micro hydro can be profitable in financial terms, while at others, unprofitable plants can exhibit such strong positive impacts on the lives of poor people and the environment that they may well justify subsidies. [31]

The evidence from this extensive experience shows such wide variation in terms of cost, profitability and impact, that it has often been difficult for investors and rural people to determine whether, and under what circumstances, this technology is viable and best meets their needs. Khennas et al. [18] claim that micro hydropower is likely to be more financially viable if the electricity generated can be used to supply power to a profitable cash generating enterprise.

Whilst supplying improved energy services to people for the first time is difficult, supplying such services profitably to very poor people who live far away from roads and the electricity grid poses a particularly difficult challenge. Micro hydro compares well with other energy supply technologies in these difficult markets. Despite this micro hydro appears to have been relatively neglected by donors, the private sector and governments in the allocation of resources and attention. In the past, rural electrification by means of grid extension was the option favoured by donors. More recently the fashion has switched towards photovoltaics, probably because of its higher foreign content, and the higher added value returned to the metropolitan countries.

The relative neglect of micro hydro has also been in part due to the fact that the circumstances under which it is financially profitable have not been systematically established, at least not in ways that investors find credible. In addition, while it is known that the growth and sustainability of the micro hydro sub-sector depends on certain types of infrastructure and institutional investments, it was often not clear which elements of this ‘enabling environment’ were essential, nor how they were best financed [33].

Table 2: Classification of Hydropower [2]

Type	Capacity
Large hydro	>100 MW
Medium hydro	10-100 MW
Small hydro	1-10 MW
Mini hydro	100 kW - 1 MW
Micro hydro	5 - 100 kW
Pico hydro	< 5 kW
kW (kilowatt) = 1000 Watts. MW (Megawatt) = 1,000,000 Watts)	

Over the last few decades there has been a growing realization in developing countries that micro hydropower schemes have an important role to play in the economic development of remote rural areas, specifically in mountainous regions. Depending on the end-use requirement of generated power, the output from the turbine shaft can be used directly as mechanical power or the turbines can be connected to an electrical generator or alternator to produce electricity. For many rural industrial applications such as milling, carpenter workshops or pumping water, shaft power is suitable, but many applications require conversion to electrical power. For domestic applications, like light bulbs, radios, televisions, rice cookers, heaters, refrigerators, and food processors, electricity is required. This can be achieved by delivering power directly to home via a small electrical distribution system, or by means of batteries which are charged at the power house. This system is commonly used where cost of direct electrification is prohibitive due to scattered and sparsely populated housings [2].

2.7 Micro Hydro Power System Design

The basic principle of hydropower systems is that if water can be piped from a certain level to a lower level, then the resulting water pressure can be used to perform work. If the water pressure is allowed to move a mechanical component, then that movement involves the conversion of water potential energy into mechanical energy. Hydro turbines convert water pressure into mechanical shaft power, which can be used to drive an electricity generator, a grain mill or some other useful device [8]. The system requires a sizeable flow of water and a proper change in elevation, called the effective head, which should be obtained without having to build elaborate and expensive structures. Figure 4 shows the main components of a “run-off-river” micro hydro power scheme. Each component has been described briefly below.

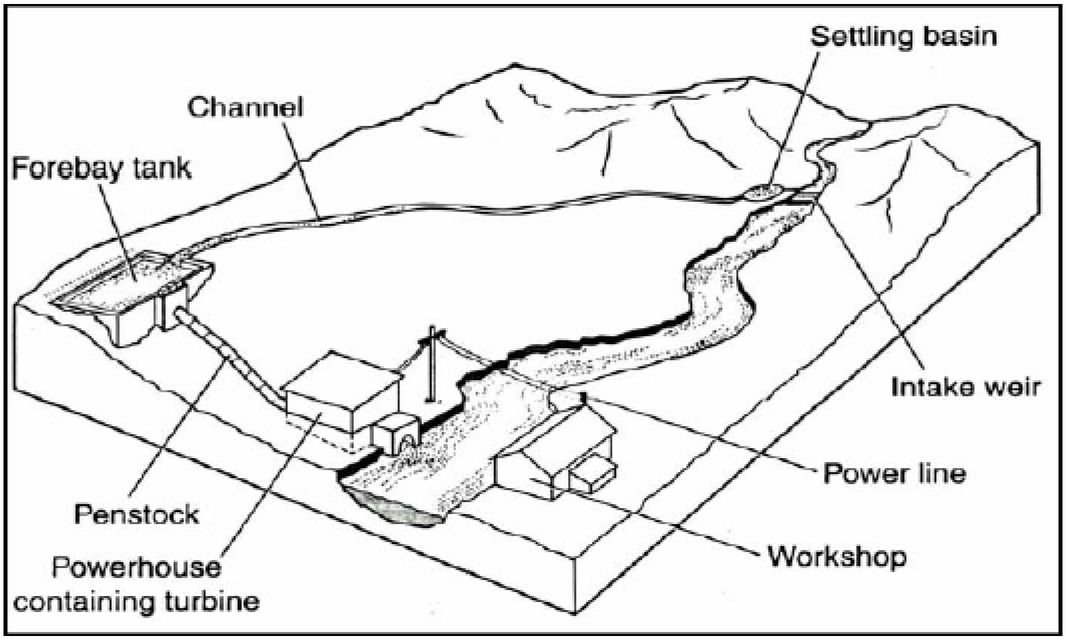


Figure 5: Layout and components of a typical micro hydropower installation. [2]

Run of the river schemes require no water storage; the water is instead diverted by the intake weir into small settling basin where the suspended sediment can settle. A grid to prevent the flow of large objects such as logs, which may damage the turbines, usually protects the intake. The diverted water is drawn via a channel into the forebay tank. The channel is usually a concrete or steel pipe along the side of a valley to maintain its elevation. The forebay tank holds sufficient water to ensure that the penstock is always fully submerged to prevent suction of air to the turbine. It also acts as water reservoir during lean season. The water flows from the forebay tank down a closed pipe called the penstock. The penstock is often made of high density materials and exposes the water to pressure; hence the water comes out of the nozzle at the end of the penstock as a high pressure jet. The power in the jet, called hydropower (a.k.a. hydraulic power), is transmitted to a turbine wheel, which changes it into mechanical power. The turbine wheel has blades or buckets, which cause it to rotate when they are struck by the water jet due to momentum transfer. Hydro-turbines convert water pressure into mechanical shaft power, which can be used to drive an electricity generator, a grain mill or some other useful device. The water returns back to the same stream via the tailrace in the powerhouse [21].

The electricity generated is delivered to load centers through a distribution system or power lines connected to the households. Depending on the generation voltage level and distance of the load centers from the power house, distribution transformers can be used for stepping up (at the source) and stepping down (at the end user) voltage.

The installed capacity and energy output is calculated using standard equations:

$$P = (Q \times \rho \times H \times g \times \eta)/1000$$

Where:

P = power or installed capacity in kilowatts

Q =discharge rate in cubic meter per second

ρ = density of water in kg per cubic meter

H = effective head in meters

g = acceleration due to gravity

η = efficiency of hydro turbine generator in decimal

And Annual Output Energy (kWh) = P x hr x CF

Where:

P = power or installed capacity in kilowatts

hr = Annual continuous generating duration (8760 hours in a year)

CF = Plant Capacity Factor (typically 95% for run-of-the-river type systems)

A well designed small scale micro hydropower scheme can blend with its surrounding and have minimal negative environmental impacts. It is one of the most environmentally favorable energy conversion options available, because these schemes are run of the river not requiring damming or the creation of water reservoirs [8, 20]. However, there are still some emissions associated with the technology during other life cycle stages. The chain of manufacturing the generating and transmission equipments processes are important source of emission [12].

2.7.1 Electromechanical Components

a. Turbines

A turbine unit consists of a runner connected to a shaft that converts the potential energy in falling water into mechanical or shaft power. The turbine is connected either directly to the generator or is connected by means of gears or belts and pulleys, depending on the speed required for the generator [11]. The choice of turbine depends mainly on the head and the design flow for the proposed micro hydropower installation. All turbines tend to run most efficiently at a particular combination of speed, head and flow. In order to suit a variety of head and flow conditions, turbines are broadly divided into four groups (high, medium, low and ultra-low head) and into two categories (impulse and reaction) [29].

Impulse machines use a nozzle at the end of the pipeline that converts the water under pressure into a fast moving jet. This jet is then directed at the turbine wheel (also called the runner), which is designed to convert as much of the jet's kinetic energy as possible into shaft power. Common impulse turbines are pelton, turgo and cross-flow.

In reaction turbines the energy of the water is converted from pressure to velocity within the guide vanes and the turbine wheel itself. Examples of reaction turbines are propeller and Francis turbines.

Table 3: Turbine classification [27]

Turbine Runner	High Head (more than 100 m / 325 ft.)	Medium Head (20 to 100 m / 60 to 325 ft.)	Low Head (5 to 20 m / 16 to 60 ft.)	Ultra-Low Head (less than 5 m / 16 ft.)
Impulse	Pelton Turgo	Cross-flow Turgo Multi-jet Pelton	Cross-flow Multi-jet Turgo	Water wheel
Reaction	—	Francis Pump-as-turbine	Propeller Kaplan	Propeller Kaplan

Turbine efficiency depends on the type of turbine and the site condition of the micro hydropower plant. The efficiency usually varies from 50% to 80%. [27]

b. Generators

Generators convert the mechanical (rotational) energy produced by the turbine to electrical energy; this is the heart of any hydro electrical power system. The principle of generator operation is quite simple: when a coil of wire is moved past a magnetic field, a voltage is induced in the wire.

Alternating current (AC) generators are also referred to as alternators. They generate varying voltages, which alternate above and below the zero voltage point. It is this process that produces AC electricity.

There are two types of generators: synchronous and asynchronous. Synchronous generators are standard in electrical power generation and are used in most power plants. Asynchronous generators are more commonly known as induction generators. Both of these generators are available in three-phase or single-phase systems. System capacity, type of load and length of the transmission/distribution network dictate whether a single- or three-phase generator should be used [11].

Induction generators are generally appropriate for smaller systems. They have the advantage of being rugged and cheaper than synchronous generators.

The induction generator is a standard three-phase induction motor, wired to operate as a generator.

All generators must be driven at a constant speed to generate steady power at the frequency of 60 Hz. The number of poles in the generator determines the speed, commonly stated in revolutions per minute (rpm). The more pairs of poles, the slower the speed. The 2-pole generator with a speed of 3600 rpm is too high for practical use with a micro hydropower system. The 1800-rpm 4-pole generator is the most commonly used. In order to match the speed of the generator to the low speed of the turbine, a speed increaser such as belt and/or gearbox might be needed [29].

Full-load efficiencies of synchronous generators vary from 75 to 90 percent, depending on the size of the generator. Larger generators are more efficient, and three-phase generators are generally more efficient than single-phase ones. The efficiency will be reduced by a few percentage points when being used at a particular load (e.g., at 50 percent of the load). Efficiency of induction generators is approximately 75 percent at full load and decreases to as low as 65 percent at part load. Permanent magnet DC generators have efficiencies of more than 80 percent at full load. It is crucial to take these figures into account when selecting a generator because the overall efficiency of the system will be affected. [27]

There are other factors to consider when selecting a generator for your system, such as capacity of the system, types of loads, availability of spare parts, voltage regulation and cost. If high portions of the loads are likely to be inductive loads, such as motor and fluorescent lights, a synchronous generator will be better than an induction generator.

c. Drive Systems

In order to generate electrical power at a stable voltage and frequency, the drive system needs to transmit power from the turbine to the generator shaft in the required direction and at the required speed. Typical drive systems in micro-hydropower systems are as follows [29]:

- **Direct drive:** A direct drive system is one in which the turbine shaft is connected directly to the generator shaft. Direct drive systems are used only for cases where the shaft speed of the generator shaft and the speed of the turbine are compatible. The advantages of this type of system are low maintenance, high efficiency and low cost.
- **"V" or wedge belts and pulleys:** This is the most common choice for micro-hydropower systems. Belts for this type of system are widely available because they are used extensively in all kinds of small industrial machinery.

• **Timing belt and sprocket pulley:** These drives are common on vehicle camshaft drives and use toothed belts and pulleys. They are efficient and clean-running and are especially worth considering for use in very small system drives (less than 3 kW) where efficiency is critical.

• **Gearbox:** Gearboxes are suitable for use with larger machines when belt drives would be too cumbersome and inefficient. Gearboxes have problems regarding specification, alignment, maintenance and cost, and this rules them out for micro-hydropower systems except where they are specified as part of a turbine-generator set.

d. Electronic Load Controllers

Water turbines, like petrol or diesel engines, will vary in speed as load is applied or disconnected. Although not a great problem with machinery that uses direct shaft power, this speed variation will seriously affect the frequency and voltage output from a generator. It could damage the generator by overloading it because of high power demand or over-speeding under light or no-load conditions [29].

Traditionally, complex and costly hydraulic or mechanical speed governors similar to larger hydro systems have been used to regulate the water flow into the turbine as the load demand varied. Over the last two decades, electronic load controllers (ELCs) have been developed that have increased the simplicity and reliability of modern micro hydropower systems.

An ELC is a solid-state electronic device designed to regulate output power of a micro-hydropower system. Maintaining a near-constant load on the turbine generates stable voltage and frequency. The controller compensates for variation in the main load by automatically varying the amount of power dissipated in a resistive load, generally known as the ballast or dump load, in order to keep the total load on the generator and turbine constant. Water heaters are generally used as ballast loads. An ELC constantly senses and regulates the generated frequency. The frequency is directly proportional to the speed of the turbine [11].

Voltage control is not required for synchronous generators because they have a built-in automatic voltage regulator. Without an ELC, the frequency will vary as the load changes and, under no-load conditions, will be much higher than rated frequency. ELCs react so fast to load changes that speed changes are not even noticeable unless a very large load is applied. The major

benefit of ELCs is that they have no moving parts, are reliable and are virtually maintenance-free. The advent of ELCs has
allowed the introduction of simple and efficient multi-jet turbines for micro-hydropower systems that are no longer burdened by expensive hydraulic governors.

ELCs can also be used as a load-management system by assigning a predetermined prioritized secondary load, such as water heating, space heating or other loads. In this way, you can use the available power rather than dumping it into the ballast load. It can be used to connect loads by priority sequence.

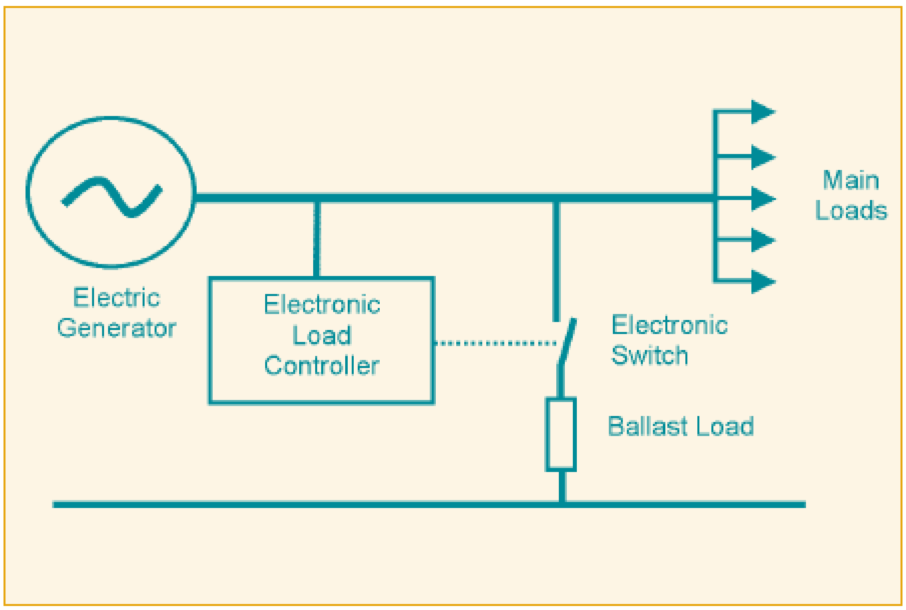


Fig.6: Schematic Diagram for connection of ELC [27]

2.8 The Way forward for Rural Electrification through Hydropower

Africa's energy needs are urgent and huge investments are needed. While Africa needs reliable electricity supplies to stimulate economic growth and industrialization, the
majority of the population could miss out if no significant and sustained effort is made to reach them. The capital costs of large hydropower projects are huge and can be a real drain on the resources of poor nations [10]. There is a danger that too much reliance is put on what is often a rather elusive 'trickle down' effect from economic development based on large electricity projects.

In reality, the poor often see little benefit. The reality is that despite a variety of electrification initiatives, current forecasts are for an increase in the number of Africans without access to electricity, rather than a decrease. This situation is unacceptable. Poverty reduction must be a major focus of energy strategies.

Africa's hydropower potential is considerable, both for centralized and decentralized applications [6]. However, the risks of major social and environmental impacts from badly designed projects, large and small, in the wrong places cannot be neglected. The environmental impacts are closely linked to health and livelihoods and addressing them is not a luxury but a necessity. Lessons from past mistakes should be learnt and applied to ensure better projects in the future. We recognize that other energy sources have their own impacts; hence a comprehensive options assessment which weighs up economic, environmental and social costs and benefits is vital. A particular, directed effort is needed to reduce people's reliance on burning solid fuels through alternatives such as providing micro hydropower.

There are large institutional, financial and capacity barriers to achieving sustainable energy projects and programmes in Kenya but a concerted effort by all relevant actors, be they governments, developers, financiers, NGOs or local communities, can address and overcome these. As noted by Khennas [19], regardless of the financing mechanisms or the strategies of governments and aid agencies, the critical factors for micro hydropower development have been the existence of these individuals or agencies that have had the skill to put the various elements of a micro hydro project together (technology, finance, project management, institutional structures) and the tenacity to see it through to operation. The success of the community-based model will depend on the institutional linkages put in place to achieve sustainability [3].

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Research Design

The research applied the exploratory design where the existing micro hydropower systems in the Mt. Kenya Region, especially in Meru and Kirinyaga districts were evaluated as case studies.

The following research instruments were used in collecting the necessary technical and institutional data on the sampled micro hydropower systems;

a. Questionnaires (see appendix III, IV and V for sample questionnaires)
b. Field surveys (i.e. field visits to selected micro hydropower sites).
c. Focus groups (i.e. organisations and community members involved in the setting up and management of the micro hydropower systems).
d. Review of existing literature (i.e. from the stakeholders in the energy sector)
e. Professional interviews (i.e. engineers involved in the development of micro hydropower systems).

3.2 Sampling

Although many parts of Kenya (especially Mt. Kenya, Rift valley, Nyanza and Western Provinces) have great potential for hydro based power systems, the research was done in the Mt. Kenya region as it has more concentration of rivers and is also home to the majority of the existing and pilot community based micro hydropower systems. Therefore it was envisaged that this sample was sufficient to yield results that best reflects the potential existing in Kenya in terms of micro hydropower system as a compliment to rural electrification.

3.3 Data Analysis Plan

The research was based on primary and secondary data, information gathered through key informant interviews, questionnaires, field observations, and insights from the literature to address my research question.

3.3.1 Response from Questionnaires

The filling of the questionnaires was conducted in two ways as follows;

i. The researcher filled some of the questionnaires by directly interviewing respondents during field surveys

ii. The rest of the questionnaires were given to the respective community project chairmen who distributed to members to fill. The questionnaires were later collected by the researcher.

The number of questionnaires used was about 50% of the homes with membership to the respective micro hydropower schemes. The response from the questionnaires is summarized in table. 4.

Table 4

S/no	MHP plant	No. of Questionnaires dispatched	No. of Questionnaires returned filled	Response percentage (%)
1	Tungu Kabiri	100	80	80
2	Thiba	100	75	75
3	Ngewa	50	40	80
4	Ndiara	100	85	85
Average Response percentage				80

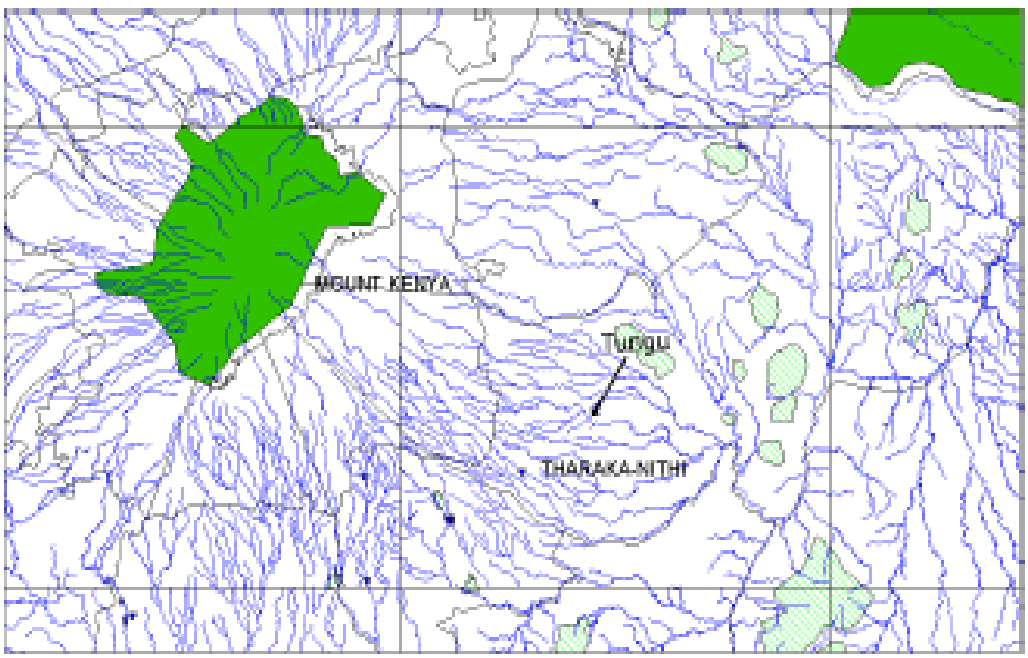
The income, electricity consumption, and expenditure data has been used to analyze the socio-economic significance of access to electrification in rural Mt Kenya water catchment area. Insights from various literature sources, information gathered through key informant interviews and on- site observations has assisted in assessing the institutional, technical, environmental and financial policies put in place for the sustainable management of the micro hydropower schemes. Any deficiencies were identified and their impact on the sustainability of the schemes assessed. The data collected was processed and analyzed.

The viability of the surveyed micro hydropower projects was assessed by using the payback period method. Depreciation of the micro hydropower plants was determined using the straight-line depreciation method. This is because straight-line depreciation is the simplest and most-often-used technique, in which the salvage value of the asset is estimated at the end of the period during which it will be used to generate revenues (useful life) and will expense a portion of original cost in equal increments over that period. [27]

CHAPTER 4
FINDINGS AND DISCUSSIONS

4.2 Tungu Kabiri Micro-Hydro Power Project

The Department of Renewable Energy, Ministry of Energy and Intermediate Technology Development Group – East Africa (ITDG-EA – an NGO) with funding from the United Nations Development Programme (UNDP) GEF Small Grants Programme implemented the Tungu Kabiri Micro Hydro Power Scheme. This project is located in Mbuiru Village, Meru South District, about 185 km north of Nairobi and 12 km from Chuka town on the Chuka Tharaka road. ITDG East Africa partnered with the Ministry of Energy in developing the technology and training the villagers in the development of the micro hydro. The project was installed in 1998 and commissioned in 1999.



Map Showing Location of the Project

Fig. 7: Map Showing Location of the micro Hydro project

The project generates 18 kW of electricity and covers a radius of 3 km with 200 households connected to power, a community otherwise not accessible through the national grid. The community contributed free labour for building the weir, digging the canal, and building the power house, among others. The participation of the community in the construction enables them to both own the project and maintain it thus ensuring its continuity. (For more on survey data, refer to table 1 appendix II)

4.1.1 The Technical, Financial and Environmental Assessment of the Power Plant

a. Technical Assessment

The technical condition and sustainability was assessed in terms of installation, operation and maintenance of the power plant and the transmission and distribution network.

i. Installation

From the field survey, it was established that the installation phase of Tungu Kabiri Micro hydro power plant did not face significant delays due to ready availability of funds from the funding organisation, the United Nations Development Programme (UNDP) GEF Small Grants Programme. There was also full cooperation from the Ministry of Energy and the community members who volunteered in providing labour in the construction of the power plant.

The workmanship on the equipment installation and civil works was done in professional manner. (See photos in appendix II)

The distribution network was also well done with the standard cable and treated poles utilized (See Fig. 7 in appendix II)

ii. **Operation and Maintenance of the Power Plant**

The plant was also found to be kept very tidy. There is one caretaker assigned the task of operation and maintenance of the plant. However, it was established that he has no technical background and could not explain logically the technical processes involved. The operator's level of education is KCSE certificate and was trained on site by the project engineer during the installation and commissioning of the project. Replacement of stolen cables and poles is also done by the caretaker.

One key observation made was that people are allowed to use the channel water for other purposes such are washing of clothes and for domestic use (See Fig. 8 in appendix II). This is likely to introduce foreign materials in the water which may reach the turbine and cause serious damage. Operation and maintenance costs are as summarized in table 5.

b. Financial Assessment

The cost of the project was approximately Kshs. 100,000.00 per kilowatt of power generated resulting in a total project cost of Kshs. 1.8 million for the 18kW.

Unlike the usual supply of rural areas using the national grid which is loss making due to the transmission losses, and low consumption in rural areas, this plant is able to supply the community without being a burden on the national economy. The power generated is owned by the local community and sold to its members for lighting, curing tobacco, pumping water, battery charging among others.

The fixed monthly tariff for every household is Kshs. 200.00, generating an income of about Kshs. 40,000.00 for the 200 homes supplied with power. At the market centre, there are six shops each paying a rent of Kshs. 600.00 per month. The power is also used to drive a water supply pump to deliver water up hill to the market centre where the community members buy at Kshs.0.50 per 20litre jerrican (See Figs. 15-16 in Appendix II). The revenue from the sale of water is approximated at Kshs. 4000.00 from the 200 homes using 20 jerricans a day. (See summary in table 4)

The power is supplied during the day to the centre from 8.00 am to 6.00 pm and then supplied to the homes for lighting and powering radio and television systems as from 6 pm.

At the Market Centre, the services provided include Welding, refrigeration, battery charging, hair saloons, mobile charging, television and video entertainment. (See Figs. 11-14 in Appendix II)

Table 5: Monthly Revenue Generated

S/No	Income generating Activity	Number of Activities/Items/homes	Revenue per Activity/item/home (Kshs)	Total Revenue (Kshs)
1	Electricity use in Homes	200	200	40,000.00
2	Rent from the shops at the	6	600	3,600.00

	market centre			
3	Sale of water at the water point for 200 homes at average usage of 20 jerrican per home per day	200x20 = 4000	0.5	60,000.00
4	Total Monthly Revenue			103,600.00

Total Annual Revenue = Total Monthly Revenue x 12

= 103600 x 12

= 1,243,200.00

Table 6: Annual Operation and Maintenance Costs

S/No	Activity/Item	Cost (Kshs)	Remarks
1	Salary of caretaker/technician	24,000.00	Monthly payment is 2000.00
2	Spare parts (i.e. pulleys) and servicing (i.e. greases)	18,000.00	An average cost of 1500.00 per month
3	Distribution line maintenance (i.e. fallen/stolen poles and cables)	12,000.00	An average cost of 1000.00 per month
4	Depreciation cost (See calculation in Appendix VI)	81,000	Useful life of a micro hydros is about 20 years [7, 23].
	Total Annual O&M costs	**135,000.00**	

Net Annual Revenue = Total Annual Revenue - Total Annual O&M costs

= 1,243,200.00 - 135,000.00

= 1,108,200.00

$$\text{Payback Period} = \frac{Cost\ of\ the\ Project}{Net\ Annual\ Revenue}$$

$$= \frac{1,800,000}{1,108,200}$$

= 1 Year and 8 Months

A Case of Supply of the Excess Power to the National Grid – Impact on the Annual Revenue and Pay back Period.

From the field survey, it was established that for about 8 hours the entire power generated from Tungu Kabiri power plant is dumped using electrical coils/heaters. Table 7below shows the additional revenue that would have been generated were the power plant interconnected to the grid under the feed-in-tariffs policy by the Ministry of Energy [24].

Table 7: Additional Annual Revenue from Sale of Excess Power to KPLC

Income generating activity	Power generated (kW)	No. of hours Generated Power is entirely Dumped	Approximated energy available for feed-in to the grid (kWh)	Feed-in-Tariff (Kshs)	Annual revenue Generated (Kshs)	Remarks
Sale of Excess Power to the National Grid	18	8	144	8	(144x8x335) = 385,920.00	An allowance of 30 days for minor breakdowns and routine maintenance has been assumed, thus subtracted from 365 days to get 335 days

Revised Net Annual Revenue = 1,108,200.00 + 385,920.00

= 1,494,120.00

$$\text{Revised Payback Period} = \frac{Cost\ of\ the\ \mathrm{Pr}oject}{Net\ Annual\ \mathrm{Re}venue}$$

$$= \frac{1,800,000}{1,494,120}$$

= 1 Year and 2 ½ Months

The impact of the increased revenue from the sale of excess power to the national grid is that the payback period is reduced from 1 year and 8 months to 1 year and 2months, hence making the investment more profitable, viable and sustainable.

c. Environmental Impact

The micro hydro power plant has no major impact on the environment as it is a run-off-river type of plant. However, during the dry seasons, the water level in the Tungu River reduces significantly affecting the water volume and subsequently the power generation.

4.2 Thiba Micro Hydro Power Project

This project is located in Kianyaga area, Kirinyaga District, about 15 km from Kerugoya town. The installation started in 2002 and the project commissioned in 2005.

The project generates 132 kW of electricity and covers a radius of 5 km with 120 households connected to power. The project cost approximately Kshs. 35 million which was all from the community members contributions save for about Kshs. 3 million from the Gichugu Constituency Development Fund. This translates to Kshs. 265,151.00 per kW.

The community contributed free labour for building the weir, digging the canal, and building the power house, among others. The participation of the community in raising the cost of the project and construction of the power plant ensures that they own the project and maintain it thus enabling its sustainability. Currently the project has 1000 members. (For more on survey data, refer to table 2 appendix III)

4.2.1 The Technical, Financial and Environmental Assessment of the Power Plant

a. Technical Assessment

The technical condition and sustainability was assessed in terms of installation, operation and maintenance of the power plant and the transmission and distribution network.

i. Installation

The installation phase of the plant commenced in 2002 and continued until 2005 when it was completed and the project commissioned. The project was well planned, structured, although it experienced delays in implementation due to cash flow problems as the community members contributed the funds in phases as they could not manage to pay the whole amount at once. The delay was also attributed to political interference resulting from feuding local politicians over the control of the project.

The workmanship on the installations and the civil works was professionally done as depicted by the finishing on the intake, canal, penstock, power plant, the control instruments and the distribution network. (See photos in Appendix III)

ii. Operation and Maintenance of the Power Plant and the Distribution Network

The power plant and the distribution network are well maintained. The plant was also found to be kept very tidy. The control systems such as electronic load controllers and the excess power dumpers (ballasts) are of the state of the art and were professionally installed. (See Figs. 24-26 in Appendix III)

There are two trained technicians employed for operation and maintenance of the plant. The work in shifts and are paid monthly salary of Kshs. 3000.00 each.

The power plant is managed by the project Chairman elected by the community. The chairman is assisted by the project treasurer in the monthly collection of power consumption payment of Kshs. 300.00 per household. The households are required to use 8W energy saving bulbs. Whenever the plant breaks down, money from the project fund made of the monthly contributions is used to buy new spares. If the money is not enough, the project chairman calls a community members meeting where the issue is discussed and the cost divided equally amongst the members. However it was established during the survey that major breakdowns are rare save for routine maintenance involving changing the pulley, greasing and the general cleaning of the plant machinery. (See Fig. 29-30 in Appendix III). Summary of operation and maintenance costs is shown in table 7.

b. Financial Assessment

The cost of the project was approximately Kshs. 35 million, translating to Kshs. 265,151.00 per kW of power generated.

Unlike the usual supply of rural areas using the national grid which is loss making due to the transmission losses, and low consumption in rural areas, this plant is able to supply the community without being a burden on the national economy. The power generated is owned by the local community and sold to its members for lighting, and powering Radio and Television systems.

The fixed monthly tariff for every household is Kshs. 300.00, generating an income of about Kshs. 36,000.00 monthly for the 120 homes supplied with power (See summary in table 8). There is no other income generating activity derived from the plant. The power generated is supplied to the homes for lighting, powering of radio systems and television from 6 pm.

Table 8: Monthly Revenue Generated

S/No	Income generating Activity	Number of Activities/Items/homes	Revenue per Activity/item/home (Kshs)	Total Revenue (Kshs.)
1	Electricity use in Homes	120	300	36,000.00
2	Rent from the shops	-	-	-
4	Total Monthly Revenue			36,000.00

Total Annual Revenue = Total Monthly Revenue x 12

= 36000 x 12

= 432,000.00

Table 9: Approximate Annual Operation and Maintenance Costs

S/No	Activity/Item	Cost (Kshs.)	Remarks
1	Salary of caretaker/technician	72,000.00	Monthly payment is 6000.00
2	Spare parts (i.e. pulleys) and servicing (i.e. greases)	24,000.00	An average cost of 2000.00 per month
3	Distribution line maintenance (i.e. fallen/stolen poles and cables)	12,000.00	An average cost of 1000.00 per month
4	Depreciation cost (See calculation in Appendix VI)	1,575,000.00	Useful life of a micro hydro is about 20 years [7, 23]
	Total Annual O&M costs	1,683,000.00	

Net Annual Revenue = Total Annual Revenue - Total Annual O&M costs

= 432,000.00 - 1,683,000.00

= - 1,251,000.00

Payback Period = $\frac{Cost\ of\ the\ Project}{Net\ Annual\ Revenue}$

= $\frac{35,000,000}{-1,251,000}$

= Payback not possible

A Case of Supply of the Excess Power to the National Grid – Impact on the Annual Revenue and Pay back Period.

From the field survey, it was established that for about 18 hours the entire power generated from Thiba power plant is dumped using electrical coils/heaters. Table 10 below shows the additional revenue that would have been generated were the power plant interconnected to the grid under the feed-in-tariffs policy by the Ministry of Energy [24].

Table 10: Additional Annual Revenue from Sale of Excess Power to KPLC

Income generating activity	Power generated (kW)	No. of hours Generated Power is entirely	Approximated energy available for feed-in to the grid (kWh)	Feed-in-Tariff (Kshs)	Annual revenue Generated (Kshs)	Remarks

		Dumped				
Sale of Excess Power to the National Grid	132	18	2376	8	(2376x8x335) = 6,367,680.00	An allowance of 30 days for minor breakdowns and routine maintenance has been assumed, thus subtracted from 365 days to get 335 days

Revised Net Annual Revenue = - 1,251,000.00 + 6,367,680.00

= 5,116,680.00

$$\text{Revised Payback Period} = \frac{Cost\ of\ the\ \mathrm{Pr}oject}{\mathrm{Re}visedNet\ Annual\ \mathrm{Re}venue}$$

$$= \frac{35{,}000{,}000}{5{,}116{,}680}$$

= 6 years and 10 months

The impact of the increased revenue from the sale of excess power to the national grid is that the payback period is now tenable at 6 years and 10 months, hence making the investment profitable, viable and sustainable. It is noteworthy that with only domestic consumption of the power generated, the Thiba power plant is completely unprofitable with any payback not possible.

c. Environmental Impact

The micro hydro power plant has no major impact on the environment as it is a run-off-river type of plant. However during the prolonged dry seasons being experienced nowadays due to climate change, the water level and flow rate of the Thiba River reduces resulting in reduced power output from the Thiba micro hydro power plant. The blue gum and eucalyptus trees along the river bank are an environmental threat as they draw a lot of water resulting in reduced water level. (See Fig. 31 background in Appendix III)

4.3. Ngewa Micro Hydro Power Project

This project is located in Ng'ewa village near Kangari town in Murang'a South District. The installation started in 2000 and the project commissioned in 2004.

The project generates 15 kW of electricity and covers a radius of 2 km with 100 households connected to power. The project cost approximately Kshs. 1.4 million which was all from the community members contributions.

The community contributed free labour for building the weir, digging the canal, and building the powerhouse, among others. The participation of the community in raising the cost of the project and construction of the power plant ensures that they own the project and maintain it thus enabling its sustainability. Currently the power is supplied to 100 members. (For more on survey data, refer to table 3 appendix IV)

4.3.1 The Technical, Financial and Environmental Assessment of the Power Plant

a. Technical Assessment

The technical condition and sustainability was assessed in terms of installation, operation and maintenance of the power plant and the transmission and distribution network.

i. Installation

The installation phase of the plant commenced in 2000 and continued until 2004 when it was completed and the project commissioned. The project was not well planned and experienced delays in implementation due to cash flow problems as the community members contributed the funds in phases at they could not manage to pay at once. They delay was also attributed to local political interference resulting from feuding local politicians over the control of the project.

The workmanship on the installations and the civil works was shoddily done as depicted by the finishing on the power plant, the generating equipment, control instruments and the distribution network. (See photos in Appendix IV)

ii. Operation and Maintenance of the Power Plant and the Distribution Network

The power plant and the distribution network are not well maintained. The powerhouse was also found to be filthy with sand bags placed over the rusty equipment. (See Figs.36-37 in Appendix IV).The control systems such as electronic load controllers and the excess power dumpers (electric coils) were found wanting in terms of installation and maintenance. The coils were exposed and dangerously hanging on the wall (See Fig. 39 in Appendix IV). This can be dangerous to the people who operate and maintain the plant and even the visitors. The exposed coils when they heat up can even cause fire in the powerhouse.

There is no trained technician employed for operation and maintenance of the plant. However there is a caretaker who is paid Kshs. 1000.00 per month. The power plant is managed by the project Chairman elected by the community. The chairman is assisted by the project treasurer in the monthly collection of power consumption payment of Kshs. 100.00 per household.

The households are required to use four 8W energy saving bulbs and one socket one Radio system and one TV. The TV must be black and white.

The monthly members' contribution is utilized for purchase of spares for replacement of the spoiled or worn out components. Summary of operation and maintenance costs is shown in table 12.

b. Financial Assessment

The cost of the project was approximately Kshs. 1.4. million resulting to Kshs. 93,333.00 per kilowatt of power generated.

The power generated is owned by the local community and supplied to members for evening lighting from 6.00 pm to 6.00 am the next morning. However, the actual use is from 6 pm to around midnight.

The fixed monthly tariff for every household is Kshs. 100.00, generating an income of about Kshs. 10,000.00 for the 100 homes supplied with power as shown in table 11.

Table 11: Monthly Revenue Generated

S/No	Income generating Activity	Number of Activities/Items/homes	Revenue per Activity/item/home (Kshs.)	Total Revenue (Kshs.)
1	Electricity use in Homes	100	100	10,000.00
2	Rent from the shops	-	-	-
4	Total Monthly Revenue			10,000.00

Total Annual Revenue = Total Monthly Revenue x 12

= 10000 x 12

= 100,000.00

Table 12: Approximate Annual Operation and Maintenance Costs

S/No	Activity/Item	Cost (Kshs.)	Remarks
1	Salary of caretaker/technician	12,000.00	Monthly payment is 1000.00
2	Spare parts (i.e. pulleys) and servicing (i.e. greases)	6,000.00	An average cost of 500.00 per month
3	Distribution line maintenance (i.e. fallen/stolen poles and cables)	3,600.00	An average cost of 300.00 per month
4	Depreciation cost (See calculation in Appendix VI)	63,000.00	Useful life of a micro hydro is about 20 years [7, 23]
	Total Annual O&M costs	84,600.00	

Net Annual Revenue = Total Annual Revenue - Total Annual O&M costs

$$= \quad 100{,}000.00 - 84{,}600.00$$

$$= \quad 15{,}400.00$$

$$\text{Payback Period} \quad = \quad \frac{Cost\ of\ the\ \mathrm{Pr}oject}{Net\ Annual\ \mathrm{Re}venue}$$

$$= \quad \frac{1400{,}000{,}000}{15{,}400}$$

$$= \quad 90 \text{ Years}$$

A Case of Supply of the Excess Power to the National Grid – Impact on the Annual Revenue and Pay back Period.

From the field survey, it was established that for about 18 hours the entire power generated from Ngewa power plant is dumped using electrical coils/heaters. Table 13 shows the additional revenue that would have been generated were the power plant interconnected to the grid under the feed-in-tariffs policy by the Ministry of Energy [24].

Table 13: Additional Annual Revenue from Sale of Excess Power to KPLC

Income generating activity	Power generated (kW)	No. of hours Generated Power is entirely Dumped	Approximated energy available for feed-in to the grid (kWh)	Feed-in-Tariff (Kshs)	Annual revenue Generated (Kshs)	Remarks
Sale of Excess Power to the National Grid	15	18	270	8	(270x8x335) = 723,600.00	An allowance of 30 days for minor breakdowns and routine maintenance has been assumed, thus subtracted from 365 days to get 335 days

$$\text{Revised Net Annual Revenue} = \quad 15{,}400.00 + 723{,}600.00$$

$$= \quad 739{,}000.00$$

Revised Payback Period = $\dfrac{Cost\ of\ the\ Project}{Net\ Annual\ Revenue}$

$$= \frac{1{,}400{,}000}{739{,}000}$$

= 1Year and 11 months

The impact of the increased revenue from the sale of excess power to the national grid is that the payback period is significantly reduced from 90 years to 1 year and 11months, hence making the investment more profitable, viable and sustainable.

c. Environmental Impact

The Ngewa micro hydro power plant has no major impact on the environment, as it is a run-off-river type of plant. It is also not adversely affected by the changes in the environment caused by the seasonal variations in the flow of the river. However during the prolonged dry seasons being experienced nowadays due to climate change, the water level and flow rate of the Ngewa River reduces resulting in reduced power output.

4.4. Ndiara micro Hydro Power Project

This project is located in Ndiara village, Mathioya Division in Murang'a North District. The installation started in June 2006 and the project commissioned in October 2007.

The project generates 7.5 kW of electricity and covers a radius of 2 km with 200 households connected to power. The project cost approximately Kshs. 1.75 million, which was all from the community members' contributions.

The community contributed free labour for building the weir, digging the canal, and building the powerhouse, among others. The participation of the community in raising the cost of the project and construction of the power plant ensures that they own the project and maintain it thus enabling its sustainability. Currently the project has 200 members. (For more on survey data, refer to table 3 appendix V)

4.4.1 The Technical, Financial and Environmental Assessment of the Power Plant

a. Technical Assessment

The technical condition and sustainability was assessed in terms of installation, operation and maintenance of the power plant and the transmission and distribution network.

ii. Installation

The installation phase of the plant commenced in June 2006 and continued until October 2007 when it was completed and the project commissioned. The project was well planned, structured, although it experienced delays in implementation due to cash flow problems as the community members contributed the funds in phases at they could not manage to pay at once.

The workmanship on the installations and the civil works was well done as depicted by the finishing on the intake, canal, penstock, power plant, the control instruments and the distribution network. (See photos in Appendix V)

ii. Operation and Maintenance of the Power Plant and the Distribution Network

The power plant and the distribution network are well maintained. The plant was also found to be kept very tidy. The control systems such as electronic load controllers and the excess power dumpers (electric coils) were found wanting in terms of installation and maintenance. The coils were exposed and dangerously hanging on the wall (See Fig. 39 in Appendix IV). This can be dangerous to the people who operate and maintain the plant and even the visitors. (See Figs. 50-51 in Appendix V)

There is no trained technician employed for operation and maintenance of the plant. However there is a caretaker who is paid Kshs. 1200.00 per month. The power plant is managed by the project Chairman elected by the community. The households are required to use five-8W energy saving bulbs and one socket, a radio system and black and white TV.

Major breakdowns are rare save for routine maintenance involving replacement of belts, burnt dump coils and greasing. (See operation and maintenance costs in table 15)

b. Financial Assessment

The cost of the project was approximately Kshs. 1.75 million, translating to Kshs. 233,333.00 per kW of power generated.

The power generated is supplied to members in the evenings from 6.00 pm to 6.00 am the next morning. However, the actual use is from 6 pm to around midnight.

The fixed monthly tariff for every household is Kshs. 100.00, generating an income of about Kshs. 20,000.00 for the 200 homes supplied with power. There are 2 shops using the power at a monthly tariff of Kshs. 300.00. (See summary of revenue in table 14)

Table 14: Monthly Revenue Generated

S/No	Income generating Activity	Number of Activities/Items/homes	Revenue per Activity/item/home (Kshs)	Total Revenue (Kshs.)
1	Electricity use in Homes	200	100	20,000.00
2	Rent from the shops	2	300	600.00
4	Total Monthly Revenue			26,000.00

Total Annual Revenue = Total Monthly Revenue x 12

= 26000 x 12

= 312,000.00

Table 15: Approximate Annual Operation and Maintenance Costs

S/No	Activity/Item	Cost (Kshs.)	Remarks
1	Salary of caretaker/technician	14,400.00	Monthly payment is 1200.00
2	Spare parts (i.e. pulleys) and servicing (i.e. greases)	6,000.00	An average cost of 500.00 per month
3	Distribution line maintenance (i.e. fallen/stolen poles and cables)	6,000.00	An average cost of 500.00 per month
4	Depreciation cost (See calculation in Appendix VI)	78,750.00	Useful life of a micro hydro is about 20 years [7, 23]
	Total Annual O&M costs	105,150.00	

Net Annual Revenue = Total Annual Revenue - Total Annual O&M costs

= 312,000.00 - 105,150.00

= 206,850.00

Payback Period = $\frac{Cost\ of\ the\ \mathrm{Pr}oject}{Net\ Annual\ \mathrm{Re}venue}$

= $\frac{1{,}750{,}000{,}000}{206{,}850}$

= 8 Years and 6 Months

A Case of Supply of the Excess Power to the National Grid – Impact on the Annual Revenue and Pay back Period.

From the field survey, it was established that for about 18 hours the entire power generated from Ndiara power plant is dumped using electrical coils/heaters. Table 16 below shows the additional revenue that would have been generated were the power plant interconnected to the grid under the feed-in-tariffs policy by the Ministry of Energy [24].

Table 16: Additional Annual Revenue for Sale from Excess Power to KPLC

Income generating activity	Power generated (kW)	No. of hours Generated Power is entirely Dumped	Approximated energy available for feed-in to the grid (kWh)	Feed-in-Tariff (Kshs)	Annual revenue Generated (Kshs)	Remarks
Sale of Excess Power to the National Grid	7.5	18	135	8	(135x8x335) = 361,800.00	An allowance of 30 days for minor breakdowns and routine maintenance has been assumed, thus subtracted from 365 days to get 335 days

Revised Net Annual Revenue = 206,850.00 + 361,800.00

= 568,650.00

Payback Period = $\frac{Cost\ of\ the\ \mathrm{Pr}oject}{Net\ Annual\ \mathrm{Re}venue}$

= $\frac{1{,}750{,}000}{568{,}650}$

= 3 years and 9 months

The impact of the increased revenue from the sale of excess power to the national grid is that the payback period is reduced from 8 years and 6 months to 3 year and 9 months, hence making the investment more profitable, viable and sustainable.

c. Environmental Impact

The Ndiara micro hydro power plant has no major impact on the environment, as it is a run-off-river type of plant. However during the prolonged dry seasons being experienced nowadays due to climate change, the water level and flow rate of the Ndiara River reduces resulting in reduced power output.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

While the data collected might not be very exhaustive, as it was not possible to cover all the micro hydros in Mt. Kenya water catchment area due to constraint of time and resources, it is my belief that what was covered represents complete comparative review of the micro hydropower projects across a range of different areas in the larger Mt. Kenya water catchment area.

5.1.1 Technical Condition and Sustainability

Micro-hydro power technology is now a mature technology that has benefited from substantial improvements in the last 30 years worldwide and particularly the last 10 years in Kenya.

The evidence from the field survey shows a wide variation in terms of cost, profitability and impact, making it difficult for the various communities involved in determining whether, and under what circumstances, this technology is viable and best meets their needs. However, it is noticeable that projects that were better planned, though more expensive, exhibits high quality equipment used, good workmanship and overall superior implementation, operation and maintenance.

Community members interviewed said that although the national grid is available, they still preferred using the power from the micro hydro plant as it is affordable and also a symbol of pride for the efforts of the community members in fostering socio-economic development. It is also expensive for the community members to connect to the national grid as the costs vary with the proximity to the power line and in some instances requires purchase of a transformer.

The micro hydropower project cost could be reduced by using locally fabricated equipment as opposed to importation from abroad. For instant Turbines can easily be fabricated locally. However, this requires substantive investment in the training of local human resources and ensuring that funds required for starting small and medium enterprises in this field are easily accessible.

5.1.2 Financial Viability and Sustainability

The financial viability of a micro hydropower in the Mt. Kenya water catchment area is dependent on the economic use of the power generated and the level of the subsidies from the government. The revenue from the energy sales for domestic consumption alone will not be sufficient to meet the combined costs of the operation and routine maintenance, and major repair and replacement of turbine, generator and spare parts.

The study has also shown that if the community members do not utilize the power from the micro hydropower systems in revenue generating ventures but only use it for lighting, then the sustainability of the projects will be under threat. As shown in table 16, interconnection to the national grid is a viable option that increases the revenue and payback periods of the power plants, hence making them profitable and sustainable. For example, Thiba micro hydropower plant that is totally unprofitable despite the huge investment, if interconnected to the grid to sale the excess power, has its revenue tremendously increased and payback period of only 6 years and 10 months. Another example is Ngewa micro hydro plant where the payback period can be significantly reduced from of 90 years to only 1 year and 11 months if excess power is sold to KPLC through interconnection to the grid.

Therefore, as the national grid expands through the Rural Electrification Programme (REP), it is very important that the micro hydropower systems in the Mt. Kenya Region be interconnected to the national grid to generate more revenue from the sale of excess power generated. By doing this, the return on investment for the community members will be more realistic and the micro-hydropower projects sustainable.

Table 17: Comparison of Annual Revenues and Payback Periods if Power Plants are interconnected to the Grid to Sale of Excess Power to KPLC.

Project Location	Capital Investment (Kshs)	Power Generated (kW)	Cost/kW (Kshs)	Annual Profit (Kshs)	Payback Period	Revised Annual Profit when excess power is sold to KPLC (Kshs)	Revised Payback Period when excess power is sold to the national grid
Tungu Kabiri	1.8m	18	100,000	1,108,200	1 year and 8 months	1,494,120	1 year 21/2 months
Thiba	35m	132	265,151	**(-)** 1,251,000	Non profitable	5,116,680	6 years 10 months
Ngewa	1.4m	15	93,333	15,400	90 years	739,000	1 years 11 months
Ndiara	1.75m	7.5	233,333	206,850	8 years and 6 months	586,650	3 years and 9 months

5.1.3 Environmental Impact and Sustainability

The micro hydropower plants have little impact on the environment. However for sustainability of the rivers used, community members should be encouraged to plants trees and conserve forests.

The community members should also warned against planting blue gum and eucalyptus trees along the rivers and encouraged to uproot the existing ones as these trees consume a lot of water resulting into reduced water levels or even total drying of the rivers.

There are environmental benefits due to the reduced carbon dioxide emissions that contribute to Global Warming as the community members use power from the micro hydropower systems for lighting instead of the kerosene lamps.

5.1.4 Socio-Economic Benefits of Micro Hydropower Systems

The benefits of rural electrification through micro hydropower systems cannot be ove-emphasized, especially for the enhancement of the rural peoples' livelihoods. Access to electricity in combination with simultaneous access to markets and other infrastructure has contributed to growth in rural areas in a sustainable manner. However, results from this study shows that access to electricity by itself does not significantly increase income generation. The electricity demand for productive use is insignificant as the power is mainly used for lighting and powering radio systems and television.

5.1.5 The Institutional Capacity and Policy Framework

The success of the community-based micro hydropower systems development and management is dependent on the institutional linkages put in place to achieve sustainability. With the current settings, the community will not be able to effectively manage the micro hydropower systems without the support of the government, private sector, NGOs and other institutions with interests in the energy sector. It is also worth noting that most end users have not been sufficiently informed of the benefits and limitations of micro hydropower systems, leading to many misconceptions as to the reliability of the technology and what it takes to make them sustainable.

However, the study having taken into considerations the strengths and weaknesses of the management of the micro hydropower systems, the community-based management model looks the most sustainable as long as the necessary support in terms of technical, financial, environmental and project management expertise is readily available.

5.1.6 Challenges in the Development and Management of the Micro hydro power systems

Generally, it was established during the survey that the installation, operation and maintenance of the plants, the following are the key challenges;

a. Lack of sufficient funds to meet the project cost owing to the fact that the financiers were voluntary community members in a rural setting, hence their contributions could not be set very high.
b. Political interference from feuding local politicians over the control of the project. This is because competing local political leaders easily incited some community members not to contribute towards the project.
c. Lack of or very little government support in terms of community capacity building, expertise advice and unfavourable institutional and legal framework for the community based micro-hydro power systems.
d. Lack of locally available skilled manpower for the development and management of micro hydropower systems resulting to the high cost of purchasing equipment which could easily be locally fabricated. For example turbines.

e. High cost of spare parts sometimes leads to long down time resulting to some disgruntled community members to pull out of the projects in favour of the national grid (where it is available) which is expensive.
f. Theft of equipment and distribution cables resulting in unnecessary expenses which at times the community members are unable or unwilling to meet.

5.2 Recommendations

This study has shown that most MHP plants have various technical shortcomings emanating from poor planning, implementation and management of the projects. These shortcomings need to be addressed for the existing MHP plants and for future developments, technical experts should be involved in the projects to ensure adherence to the required engineering standards.

For financial sustainability of the projects, at least the saving from the total annual income should cover the depreciation, operation and maintenance costs of the plant. Each community managed micro hydro scheme in the Mt. Kenya water catchment area has a fixed tariff that is collected monthly from the beneficiaries. Normally, all micro-hydro schemes should establish community energy fund for saving funds to be used for expenses of repair and salary of the plant operation and maintenance personnel. The savings in the community energy fund should be sufficient to ensure that the micro-hydro projects in Mt. Kenya water catchment area are able to return all investment cost during the project cycle. Nevertheless, intervention of such community based energy development approach by various organizations is important for the institutionalization of micro hydro projects in rural communities of the country.

Most of the community people are taking micro-hydro power as a substitute of kerosene lamp, so they are worried only for the bill they have to pay, they don't care about the services they would get from the micro hydro. The income generating activities can be effectively implemented if the people are encouraged to consume more electricity.

The beneficial end uses of the micro-hydro power are more place specific and mainly depended on economic situation, raw material potentiality and accessibility to the market. Therefore, the possibility of end use promotion should be taken as one of the selection criteria during the feasibility study of each micro-hydro project.

Similarly, most of the beneficiaries consider the micro hydro electricity, as a short term solution of electrification until the grid electricity is arrived to their village and are not so much serious about the depreciation cost. Therefore, the rural electrification policy should be revised. The micro hydro potential area should be identified first, and an option explored by the community members through the local development groups i.e. District Development Committees or Community Social Groups. Those who want to rely on micro-hydro for long term, priority should be given for them and the extension of grid should focus on non micro hydro area. This on one hand optimizes the national resources while equally increasing the dedication of the local community people towards the long term running of micro-hydro schemes.

Developing sustainable end uses for the produced power is an essential aspect of community- based micro hydro power development. This is because hydropower is available for use as long as the plant is running. Therefore, it is in the best interest of the communities involved in micro hydro power projects to encourage and develop income generating end uses that utilize the produced power.

From majority of the projects surveyed in the Mt. Kenya water catchment area, most consumers only use power generated for lighting and powering radio and television systems. Successful implementation of the day use distribution system will improve the power utilization significantly, increase system income, and create revenue generating enterprises.

It is important for the government and other stake holders in the energy sector to gain a better understanding of the strengths and weaknesses of the community-based management model of the micro hydropower systems in order to help enhance the formulation of the required policies for their sustainable development, management and replication.

The policies formulated should emphasize on clearly spelling out the development and management of distributed non-convectional renewable energy such as micro hydros, which otherwise might be marginalized, with preference given to building larger hydropower plants that are techno-economically cheaper per kW installed.

The government through the Ministry of Energy should spearhead and support the interconnection of the micro-hydropower plants to the national grid to enable KPLC purchase of the excess power generated. This as has been shown in table 16 will boost revenue generated from such investments hence reducing the payback period which is to the benefit of community members involved in these projects.

The regulatory framework, by institutions such as the Energy Regulatory Commission (ERC), is also important to ensure that there are policies and regulations governing the development, management, operation and maintenance of the micro hydros in order to guarantee safety and sustainability.

5.2.1 Sustainability by Profitable End-uses

It is easier to make a profitable micro hydro plant socially beneficial than to make a socially beneficial plant profitable. Profitable end-uses are difficult to develop because of the limited size of the local market and the general difficulty of small and micro enterprise development in remote locations.

Financial institutions willing to finance micro hydro should consider funding associated end-use investments in order to build profitable load. It may well be that micro hydropower systems should be promoted for its role in securing livelihoods, or developing small enterprises, rather than as an 'energy programme'.

5.2.2 Policy and Regulatory Framework

a. Policy Framework

It is recommended that the Government of Kenya should consider the following in energy sector policy regulation;

i. Need to assign clear responsibilities for micro hydro development and the development of the necessary 'enabling environment' for the provision of decentralized energy services to rural (or marginalized) communities.
ii. Need to treat all energy supply options equally ('offer the full menu of options') and to favour what best meets the needs of the consumer in different locations.
iii. Need to ensure fair competition between competing supply options and provide equal access to aid and other concessional funds, subsidies, tax breaks and support. Plans for the expansion of the electricity grid should be rule based, and in the public domain to reduce the

uncertainty about when the grid will reach a particular location. Clear rules should be published regarding the actions the grid supplier must make to compensate micro hydro owners when the grid arrives (either to buy out the plant at written down costs or to buy the hydro electricity produced).

b. Energy Regulatory Framework

It is recommended that the regulatory framework for the energy sector in Kenya should consider the following;

i. Regulation should aim at producing a structure of incentives that result in the needs of consumers being met most cost-effectively. It should be technologically neutral, and at costs that are in keeping with the scale of the investment and the ability of the various parties to pay.
ii. Regulation should be transparent, stable and free from arbitrary political interference so as to foster competition between suppliers of technology, services and finance.
iii. Regulation should set standards that are appropriate to the project cost and the ability of the various actors to pay.
iv. Quality and safety standards should be enforced to prevent the users being exploited by shoddy equipment and installations.
v. Regulations should be set so that: independent power producers can supply power to the grid at 'realistic' prices; and connection standards are appropriate for the power to be sold. Rules should be transparent and stable.

c. Environmental Regulatory Framework

In terms of the protection of the rivers, the community members should as a rule first inform the relevant regional Water Resources Management and Development Authority, under the Ministry of Water and Irrigation, to do a feasibility study in terms of area hydrology, flow and the amount of cubic litres of water applied for. The authority should only grant a license after being satisfied that the micro hydro power plant shall not significantly interfere with the natural flow of the concerned river. The authority should subsequently monitor the construction and operation of the micro hydro power plant to ensure non destruction of the water catchment areas and no threat of pollution on the rivers. The National Environmental Management Authority should also be notified to suction an Environmental Impact Assessment before commencement of a micro hydropower project.

Community members in the region should be made to appreciate that the stream generating their power cannot be allowed to run dry. So protecting the watershed of the stream was an important priority. They are should be educated to conserve the forests around the catchment areas, the important link between forest cover and rain and on replanting of forest. Every micro hydro project should be undertaken in tandem with the local office of the Water Resource Management Authority. In order to obtain these approvals, the projects must satisfy set environmental criteria and make sure that the power generation activity does not damage the surrounding nature.

The community members should also be educated against the practice of planting eucalyptus trees near the rivers and encouraged to uproot the existing ones as these trees consume a lot of water resulting into reduced water levels or even total drying of the rivers. This campaign is currently being spearheaded by the Ministry of Environment and the Ministry of Water and Irrigation.

5.2.3 Community Capacity Building

The process of developing local capacities in the design, development and management of sustainable projects takes a long time and is costly, but without such capacities micro hydropower projects will struggle to be successful. Local capacities to build micro hydro plants locally will substantially reduce costs

Local capacities to manage, operate and maintain micro hydro plants are a necessary condition for success and resources will need to be devoted to building this capacity.

5.2.4 Sustainable Management of Micro Hydro Plant

Regardless of ownership structure, it is recommended that the successful management of micro hydro plants establishes a 'corporate structure' that minimizes political interference (e.g. from municipal authorities or powerful community members) by providing clear delegated authority to a management to achieve clearly stated objectives related to profitability, coverage, and the quality of the service to be provided.

5.2.5 Addressing the Engineering Shortcomings

The research findings have shown that for the successful development and management of MHP systems, there is need to get the technology right, and develop the technical skills necessary to built, install, operate and maintain the equipment and the associated civil works.

It is therefore recommended that for technical sustainability, the following should be adhered to in the development and management of MHP plants in the Mt. Kenya water catchment area and other potential areas throughout Kenya;

a. There should be professionally conducted feasibility studies involving key stakeholders (i.e. NEMA, Engineers, Water Scientists, Surveyors) to ensure the following;
    i. Correct site selection through accurate surveys. The site survey gives more detailed information of the site conditions to allow power calculation to be done and design work to begin.
    ii. Correct estimation of hydrology (i.e. water flow rates). This data gives a good overall picture of annual rain patterns and likely fluctuations in precipitation and, therefore, flow patterns.
    iii. Correct design of the equipment and civil works (i.e. turbines, generators, canals, penstock length and the distribution network)
b. A taskforce of relevant experts should be formed to develop manuals and standards to be followed in the installation, operation and maintenance of the MHP plants.
c. Regulations should be enacted to ensure the technical staff involved in the installation, operation and maintenance of MHP plants have minimum technical qualifications, skills and experience to undertake such tasks.
d. Improvement of plant Plant/Load Factor. The load factor is the amount of power used divided by the amount of power that is available if the turbine were to be used continuously. Unlike technologies relying on costly fuel sources, the 'fuel' for hydropower generation is free and therefore the plant becomes more cost effective if run for a high percentage of the time. If the turbine is only used for domestic lighting in the evenings then the plant factor will be very low. If the turbine provides power for rural industry during the day, meets domestic demand during the evening, and maybe pumps water for irrigation in the evening, then the plant factor will be high. It is very important to ensure a high plant factor if the power plant is to be cost effective and this should be taken into account during the planning stage. Therefore the dumping of much of the generated power will be reduced if not eliminated.

e. Put in place regulations to address licensing of those involved in the development and management of MHP plants. (i.e. the owners, contractors, installers, operation and maintenance personnel).

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Appendix I

Questionnaire

A. Technical Data Questionnaire

Name of the Micro Hydropower System...

Date..

Name & Title of the Respondent...

Personal Details of the Respondent

Name of Respondent	Government /Corporate	Trader or small business operator	Technician /plant operator	Skilled or Unskilled	Farmer	Any other

Year of installation................................**Year of commissioning**....................

List of Project Sponsors

i...
ii...
iii...

1. **What is the type of the Micro Hydropower System (tick as necessary)**

Direct AC supply system..
Battery-Based system...
Other..

2. **Indicate the following micro hydropower design features;**

S/No	Parameter	Value	Units
1	Water Flow Rate		
2	Head		
3	Head Loss		

4	Water pressure		
5	Length of penstock pipe		
6	Diameter of penstock pipe		

3. **Turbine characteristics**

S/No	**Characteristic**	**Please tick as necessary**	**Remarks**
1	Type of turbine	Low head.......... Medium head....... High head.......... Other....................	
2	Turbine category	Impulse............. Reaction........... Othe.................	
	If impulse	Pelton............ Turgo............ Other.............	
	If reaction	Francis.............. Propeller................ Kaplan...................... Other....................	
	Turbine efficiency		

4. **Generator characteristics**

S/No	**Characteristic**	**Please tick as necessary**	**Remarks**
1	Type of generator	Synchronous............ Asynchronous.........	
2	Type of generator output current	AC............ DC............	
3	Generator output voltage		
4	Generator output frequency		
5	Type of drive system	Gear box................ Belts & pulleys....... Direct drive.......... Other..................	
6	Type of load controller used	Electronic................. Induction generator controller............... Distributed intelligent load	

		controller........... Other.....................	

5. **Transmission/Distribution Network**

S/No	Characteristic	Please tick as necessary	Remarks
1	Mode of transmission	Overhead................ Underground...........	
2	Mode of distribution	Overhead................ Underground...........	
3	Transmission voltage		
4	Distribution voltage		
5	Type & size of transmission cables		
6	Type & size of distribution cables		
7	Type of metering used		
8	Tariffs charged		

6. **Operation & Maintenance Costs and Annual Electricity Sales Revenue**

S/No.	Item	Quantity	Units	Unit Rate	Amount
1	**Operation and Maintenance**				
	O & M costs of electromechanical equipments				
	O & M cost of operator (man-power)				
	O & M cost of distribution lines				
	Preventive maintenance				
	Sub- total				
2	**Repair and Replacement**				
	Replacement of Turbine and Generator auxiliaries				
	Civil infrastructure				
	Sub- total				
3	**Energy Revenues per Year**				

	Electricity Sales to domestic consumers				
	Electricity sales to commercial consumers				
	Sub-total				

7. **Description of any challenges and problems related to the following areas of the micro hydropower system;**

   i. **Installation**..
   ....
   ....
   ....
   ....

   ii. **Operation**..
   ....
   ....
   ....
   ....

   iii. **Maintenance**...
   ....
   ....
   ....
   ....

   iv. **Transmission/Distribution**..
   ....
   ....
   ....
   ....

8. **Description of any effect of the micro hydropower plant to the environment;**

....
....
....
....
....
....
....

....

B. Economic Data Questionnaire

S/No.	Economic Parameter	Actual Rate	Assumed Rate	Remarks
1	Cost of installation			
2	Years in life-cycle			
3	Investment rates			
4	General inflation rate			
5	Net discount rate			
6	Present worth of repair and replacement costs			
7	Annual total generation in kWh			
8	Ratio of electricity sales per year to the total annual generation			
9	Current tariff Ksh/kWh			
10	Cost of repair and maintenance			
11	Cost of micro-grid expansion to the next customer			
12	Approximate annual savings from other fuels			

C. Electricity Consumers Questionnaire

1. Housing Unit (if possible attach picture)

Type

Permanent		Temporary	

Building Material

Wood	stone	concrete	mud	others

2. Agriculture

Area of land owned...

3.1 Type of land ownership

Owner	Rented	shared	Others

3.2 What crops/vegetables do you produce?

Rice	coffee	tea	bananas	Sweet potatoes	Miraa	other

3.3 How much did you earn last year/season from sales of agricultural produce?

(In Kenya shillings)..

4.2. . Do you own a machine?

Tractor/truck	taxi	Mills	Irrigation pump	Welding	others

3. Socio-Economic status

4.2. . Do you have a business...

If yes, what is the type of business?

Shop	workshop	Mills	construction	hawking	Other

4.2. . What is your main source of income? (list in priority)

Agriculture	livestock	salary	Remittance from relatives	business	Rental	other

4.2.1. What is your net annual income?

....

5. Energy

5.1 List your sources of energy (indicate answers by inserting x in 2nd and 3rd column)

Type of fuel	Main	Secondary
Wood		
Kerosene		
LPG (gas)		
Electricity		
Others (specify)		

5.2 Which energy type do you use for heating and cooking?

Type of fuel	Cooking	heating	Lighting & security
Wood			
Kerosene			
Diesel oil			
LPG (gas)			
Electricity			
Others (specify)			

5.3 How much did you spend on energy sources last month?

	wood	kerosene	Diesel/petrol	LPG	Electricity	others
In Kshs.						

6. Electricity

6.1 Is your house metered or point basis? (if point basis, go to question 6.3)

Metered	Point basis

6.2 Monthly consumption in kWh (request for bill if possible)

Monthly kWh	
Amount paid	

6.3 What kind of appliances do you use? (fill in numbers and wattage)

Fluorescent Lamp	Incandescent lamp	Compact fluorescent	cooker	Water boiler	TV/radio refrigerator	pumps	others

6.4 How often do you use the following appliances per day?

Fluorescent Lamp	Incandescent lamp	Compact fluorescent	cooker	Water boiler	TV/radio refrigerator	pumps	others

6.5 Do you share/split the electric usage bills? If so how much? How do you decide?

....

....

6.6 To whom do you pay the electricity bills?

Head of village	
KPLC	
Community committee	
Other	

6.7 How often do you pay?

Weekly	
Monthly	
Other	

6.8 How often do you experience power blackouts? (approximate hours)

Hourly	
Daily	
Weekly	
Monthly	
Yearly	

6.9 How long did it take to restore service last time?

1 day or less...

1 to 7 days...

More than 7 days..

6.9.1 Who did the repair work?

KPLC technicians...
Village technicians..
Private firms/technicians...

6.10 How do you contribute labour?

Mandatory..
Voluntary...
Get paid..

6.11 Do you think capacity of power generation inhibits your capacity to consume?

Yes...

No...

Can't say.......................................

6.12 Do you intent to buy more electric appliances? If so which ones?

Lighting equipments	Cooking appliances	Entertainment appliances	Power tools	others

6.13 Do you think electricity is affordable?

Current tariff	High	Low	Can't say
If increased, will you be able to afford?	Yes	No	Stop using

6.14 Who should manage the system?

Government	
KPLC	
Community	
Private	

Appendix II

Tungu Kabiri Micro Hydro Power Project Case Study

1. Survey Data

Table 1

Project Location	The project is located in Mbuiru village, Meru South District, about 185 Km North of Nairobi and about 12 Km from Chuka town, on the Chuka-Tharaka Road
Implementers	Intermediate Technology Development Group ITDG-EA The Ministry of Energy, Renewable Energy Department.
Donors	UNDP GEF Small Grants Programme Ashden Trust funded the Training component
Project Period	Started in 1998 and completed in 1999.
Cost	Cost/kW produced Kshs. 100,000
Area of Coverage	The scheme serves 200 household (1000 individuals) dotted within $3km^2$.
Area of Distribution	The power is distributed to a 1-acre plot to serve Micro-enterprises 300m away from the powerhouse.
Source of water	River Tungu

Total installed capacity	18kW
Applications	Directly benefits the community through the micro enterprise centre. Water component (water pump) added to serve the wider community Power is used to power micro-enterprises e.g. Welding, salon, barber, charging mobile phones, video showing and in future grain mill, refrigeration, water pumping, oil processing, tobacco curing. Currently 6 shops have been constructed
Technical Summary	
Gross Head	13m
Net Head	12m
Design flow	0.2 Cumecs
Penstock	Seamless mild steel Diameter: 300 mm Length: 18.45m Thickness: 4.0mm
Generating equipment	Turbine: Cross-flow - Output 18kW Generator: Synchronous, AC, 3-Phase, rated output 40kW Controller: Electronic Load Controller Ballast Load: Both Water and Air Cooled No transformer
Power house	Reinforced concrete base and masonry walls Dimensions: 4m x 4m x 3m Tail race: Open channel - Length: 3.5m

Transmission and Distribution System	
Transmission Line	4 wire 3 phase 240/415V
Cables	Transmission cables - 25mm Aluminum bare conductor
Poles	standard poles used for distribution
Tariffs	Community formulates and charge tariffs
Protection	Protective Multiple Earthing (PME) system for main line and surge arrestors
Generator	Screen protected, drip proof alternator, 40kVA, 32 kW ,415/240 Volts, 3 phase 4 wire, 50Hz at 1500rpm
Load control	ELC 240/415 volt 3 phase 20kW

2. Photos

Fig. 1 The Channel

Fig.2 The intake

Fig. 3 The Power House

Fig. 4 The generating Equipment

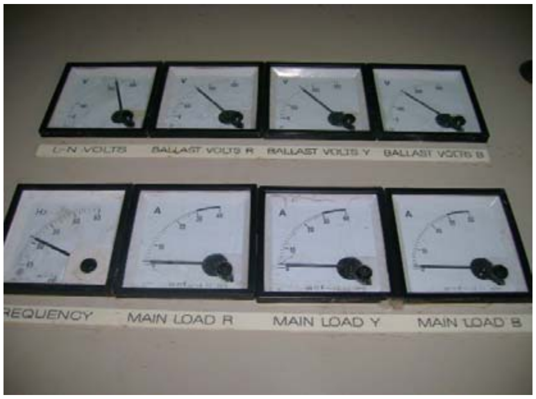

Fig. 5 The instrumentation

Fig. 6 The six 3kW each Dumpers (Ballast)

Fig. 7 The power distribution network

Fig. 8 children using the channel water for domestic purposes

Fig. 9 Tungu River – all water diverted to the channel

fig. 10 The market centre

Fig. 11 Barber Shop

Fig. 12 Battery Charging

Fig. 13Mobile phone charging

Fig. 14 Welding

Fig. 15 the water pump

Fig. 16 Wananchi fetching water

Appendix III

Thiba Micro Hydro Power Project Case Study

1. Survey Data

Table 2

Project Location	Kianyaga area, Kirinyaga District, about 15 km from Kerugoya town.
Implementers	The project was implemented by the Thiba community members with the assistance of a micro hydro installation consultant by the name Mr. David Kinyua who was the Project Engineer
Donors	The Project was fully funded by the Community members with a 3 million stipend from the local CDF fund.
Project Period	The installation was started in 2002. It was completed and commissioned in 2005
Cost	Kshs. 35 Millions
Area of Coverage	The project has about 1000 members but currently only 120 homes are connected to power
Area of Distribution	Distribution covers 5 km radius
Source of water	Thiba River
Total installed capacity	132kW
Applications	Home lighting using 8W energy saving bulbs. There is no limit to the numbers of bulbs in a house although 6A power limiter is installed in each house. Powering black and white televisions and

	radios.
Technical Summary	
Gross Head	21m
Net Head	20m
Design flow	0.95 Cumecs
Penstock	Seamless mild steel Diameter: 0.609 m Length: 33 m Thickness: 4.0mm
Generating equipment	Turbine: Cross-flow - Output 132 kW Generator: Synchronous, AC, 3-Phase Controller: Electronic Load Controller Ballast Load: Water Cooled No transformer
Power house	Reinforced concrete base and masonry walls Dimensions: 8m x 8m x 6m Tail race: Open channel - Length: 5m
Transmission and Distribution System	
Transmission Line	4 wire 3 phase 240/415V
Cables	Overhead distribution cables- 25mm Aluminum bare conductor House wiring cables- 6mm copper conductors
Poles	Standard treated poles used for distribution i.e. the KPLC standard.
Tariffs	Kshs. 15000.00 for a new member joining. Kshs. 300 per month for each member supplied with power.
Protection	PME system for main line and surge

	arrestors
Generator	Screen protected, drip proof alternator, 40kVA, 132 kW ,415/240 Volts, 3 phase 4 wire, 50Hz at 1500rpm
Load control	ELC 240/415 Volt 3 phase

2. Photos

Fig. 17 instructions post

Fig. 18 the Channel

Fig. 19 the intake

Fig. 20 outlet to the penstock

Fig. 21 the Penstock

Fig. 22 the power house

Fig. 23 the turbine and Generator

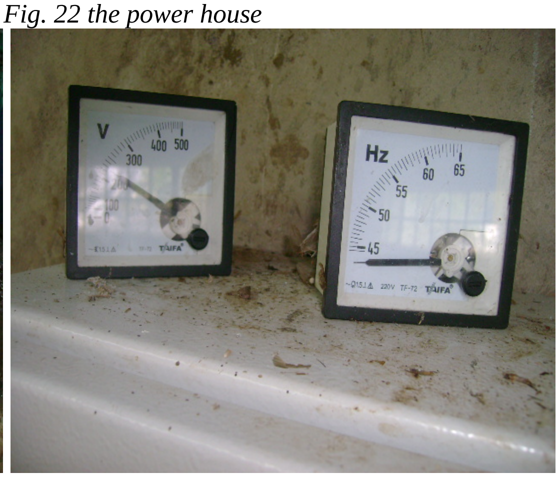

Fig. 24 instrumentation

Fig. 25 Electronic Load controller

Fig. 26 Dumpers

Fig. 27 Power Distribution

fig. 28 power supply to homes

Fig. 29 Maintenance work

Fig. 30 Turbine and Generator mounting

Fig. 31 Blue Gums along River Thiba Banks

Appendix IV

Ngewa Micro Hydro Power Project Case Study

1. Survey Data

Table 3

Project Location	The Project is located in Ng'ewa village near Kangari town in Murang'a South district.
Implementers	The project was implemented by the Ng'ewa community members with the assistant of a micro hydro installation consultant by the name Mr. Kinyua who was the Project Engineer
Donors	The Project was fully funded by the Community members
Project Period	The installation was started in 2000. It was completed and commissioned in 2004
Cost	Kshs. 1.4 Millions
Area of Coverage	The project has about 175 members but currently only 100 homes are connected to power
Area of Distribution	Distribution covers 2 km radius
Source of water	Ng'ewa River
Total installed capacity	15kW
Applications	Home lighting using 8W energy saving bulbs. Each home is allowed 4x 8W bulbs and one socket for a radio and a black and white TV.

Technical Summary	
Gross Head	15m
Net Head	14m
Design flow	0.2 Cumecs
Penstock	Length =70m Diameter = reduces from 0.2m to 0.15m to 0.1m
Generating equipment	Turbine: Cross-flow - Output 15 kW Generator: Synchronous, AC, 3-Phase Controller: Electronic Load Controller Ballast Load: air Cooled coils
Power house	Reinforced concrete base and masonry walls Dimensions: 4m x 4m x 3m Tail race: Open channel - Length: 2m
Transmission and Distribution System	
Transmission Line	2 wire 1 phase 240V
Cables	6mm copper wires
Poles	No standard poles used. Poorly prepared non-treated poles of varying sizes used. In some instances the cables are tied on trees.
Tariffs	Kshs. 11,184.00 for a new member joining. Kshs. 100 per month for each member supplied with power.
Protection	surge arrestors used at the power house
Generator	Screen protected, drip proof alternator, 15 kW , 50Hz at 1500rpm
Load control	Electronic Load Controller

2. Photos

Fig. 32 River Ngewa

Fig. 33 River Ngewa Waterfall

Fig. 34 the Penstock

Fig. 35 the Powerhouse

Fig. 36 inside the Powerhouse

Fig. 37 the turbine system

Fig. 38 Electronic Load Controller

Fig. 39 Electric Coils as Power Dumpers

Fig. 40 power Distribution System

Fig. 41 Power Distribution to Homes

Fig. 42 power connection to a household

Fig. 43 energy saving bulb

Appendix V

Ndiara Micro Hydro Power Project Case Study

1. Survey Data

Table 4

Project Location	The Project is located in Ndiara village, Mathioya Division in Murang'a North District.
Implementers	The project was implemented by the Ndiara community members with the assistant of a micro hydro installation consultant by the name Mr. David Kinyua who was the Project Engineer
Donors	The Project was fully funded by the Community members
Project Period	The installation was started in June 2006. It was completed and commissioned in October 2007
Cost	Kshs. 1.75 Million
Area of Coverage	The project has about 200 members connected to power
Area of Distribution	Distribution covers 2 km radius
Source of water	Ndiara River
Total installed capacity	7.5kW
Applications	Home lighting using 8W energy saving bulbs. Each home is allowed 5x 8Wbulbs and one socket (13A) for a radio and a black and white TV. All the house/shop wiring connected to a circuit breaker

Technical Summary	
Gross Head	9m
Net Head	8m
Design flow	0.19 Cumecs
Penstock	Length =70m Diameter = reduces from 0.2m to 0.15m
Generating equipment	Turbine: Cross-flow - Output 7.5 kW Generator: Synchronous, AC, 3-Phase Controller: Electronic Load Controller Ballast Load: air cooled coils
Power house	Reinforced concrete base and brick wall Dimensions: 4m x 4m x 3m Tail race: Open channel - Length: 2.5m
Transmission and Distribution System	
Transmission Line	2 wire 1 phase 240V
Cables	6mm copper wires
Poles	No standard poles used. Poorly prepared non-treated poles of varying sizes used.
Tariffs	Kshs. 1,850.00 for a new member joining. Kshs. 100 per month for each member supplied with power.
Protection	surge arrestors used at the power house
Generator	Screen protected, drip proof alternator, 7.5 kW , 50Hz at 1500rpm
Load control	Electronic Load Controller

2. Photos

Fig. 44 The Ndiara River

Fig. 45 Ndiara river waterfall

Fig. 46 The Intake

Fig. 47 the Powerhouse

Fig. 48 Penstock termination to Turbine

Fig. 49 the Turbine and Generator

Fig. 50 Load Control System


Fig. 51 electric coils for power dumping


Fig. 52 power distribution system


Fig. 53 energy Saving bulb in a Shop

Appendix VI

Determination of the Depreciation Costs of the Power Plants using the Straight-Line Depreciation Method

Depreciation is the reduction in the value of an asset due to usage, passage of time, wear and tear, technological outdating or obsolescence, depletion, inadequacy, rot, rust, decay or other such factors.

There are several methods for calculating depreciation, generally based on either the passage of time or the level of activity (or use) of the asset. In this research the Straight-line depreciation has been used. This is because straight-line depreciation is the simplest and most-often-used technique, in which the company estimates the salvage value of the asset at the end of the period during which it will be used to generate revenues (useful life) and will expense a portion of original cost in equal increments over that period [28].

The salvage value is an estimate of the value of the asset at the time it will be sold or disposed of; it may be zero or even negative. Salvage value is also known as scrap value or residual value [28].

$$\text{Annual Depreciation Cost} = \frac{Cost\,of\;Fixed\;Asset - Salvage\,Value}{Life\,Span\,(years)}$$

For all the projects surveyed, the salvage value was assumed to be 10% of the capital cost. Assumption guided by case studies of micro hydropower projects in China and India [4]. The useful life of the micro hydropower plants was assumed to be 20 years. The assumption was guided by published literature and interviews of key informants at Practical Action, who participated in the installation of some of the plants [7, 26].

a. Calculation of Depreciation for Tungu –Kabiri Micro Hydropower Plant

Annual Depreciation Cost = $\frac{Cost\,of\ Fixed\ Asset - Salvage Value}{Life\,Span\,(years)}$

NB: for all projects, salvage value assumed to be 10% of the capital cost and life span of 20 years [4, 7, 26].

Salvage Value = 0.1 x 1,800,000.00

= Kshs. 180,000.00

Annual Depreciation Cost = $\frac{1800000 - 180000}{20}$

= Kshs. 81,000.00

b. Calculation of Depreciation for Thiba Micro Hydropower Plant

Annual Depreciation Cost = $\frac{Cost\,of\ Fixed\ Asset - Salvage Value}{Life\,Span\,(years)}$

Salvage Value = 0.1 x 35,000,000.00

= Kshs. 3,500,000.00

Annual Depreciation Cost = $\frac{35000000 - 3500000}{20}$

= Kshs. 1,575,000.00

c. Calculation of Depreciation for Ngewa Micro Hydropower Plant

Annual Depreciation Cost = $\frac{Cost\ of\ Fixed\ Asset - Salvage Value}{Life\ Span\ (years)}$

Salvage Value = 0.1 x 1,400,000.00

= Kshs. 140,000.00

Annual Depreciation Cost = $\frac{1400000 - 140000}{20}$

= Kshs. 63,000.00

d. Calculation of Depreciation for Ndiara Micro Hydropower Plant

Annual Depreciation Cost = $\frac{Cost\ of\ Fixed\ Asset - Salvage Value}{Life\ Span\ (years)}$

Salvage Value = 0.1 x 1,750,000.00

= Kshs. 175,000.00

Annual Depreciation Cost = $\frac{1750000 - 175000}{20}$

= Kshs. 78,750.00