A Techno-economic Appraisal of Renewable Energy in Remote, Off Grid Locations in Nigeria (Obudu Ranch as a case study)

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Dissertation submitted in partial fulfilment of the requirements for the *Master of Engineering* degree at the Potchefstroom Campus of the North-West University

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November 2008

Abstract

Energy is central to economic development. It has been established that there is a clear correlation between energy consumption and living standards. Nigeria is a country of very industrious and enterprising people. However, due to non availability of adequate energy in the country, especially in the remote, off grid locations, the entrepreneurial inclination of the average Nigerian living in these locations has been largely stunted.

Over the years, successive governments in the country, in realisation of the pivotal role of energy in national development, have explored various options to improve energy supply and availability, but the situation has not experienced any remarkable improvement. This has forced many businesses and households to resort to self provision through generators, often at exorbitant costs.

This research work addresses the challenge of energy in remote, off grid locations by appraising the techno economic potential of renewable energy, using Obudu Ranch as a case study. This ranch is the foremost tourism resort in Nigeria, and has played host to a number of international events over the years. Presently, electricity is being generated through the use of diesel powered generating sets. The adjoining communities are currently without electricity, although a few of the residents have acquired generators for self provision, mostly for their domestic use. Aside the high cost associated with this, the discharge of noxious contaminants into the atmosphere is undesirable.

The research entailed a working collaboration with some notable Non Governmental Organisations (NGOs) that have done extensive ground

work in the area for access to some secondary data, as well as a number of corporate and governmental agencies that are relevant to the study.

Further, the ranch was visited to establish hands-on, the existing renewable energy sources. A trade-off of these sources was carried out with reference to a number of relevant evaluation parameters to identify the most suited option for addressing the energy challenge. A comparative analysis of this selected source was then made to establish its techno economic potential against the existing source of power generation- diesel powered generating sets, which currently costs R1.5 million annually in running expenses.

The findings from this research have established that a Renewable Energy source (mini hydro) is a more cost effective option than the diesel powered gen set, providing a 43% reduction in cost of energy generation, and a 42% reduction in the life cycle cost over the five year of analysis, compared to the status quo. In addition, it is also more environmentally friendly.

Conclusively, the findings and recommendations of this research effort, if well implemented, will be beneficial to the ranch, the adjoining communities and other relevant stakeholders.

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Acknowledgement

I acknowledge with immense gratitude the guidance and munificence of God in the execution of this work.

I also appreciate the most thorough academic I have ever met- Prof Piet Stoker for his incisive and thought provoking comments and advice, which have been of immense benefits to this research.

Sandra Stoker has also been of significant assistance with administrative support in the course of the research work.

The numerous NGOs in Cross River state of Nigeria, notably:

- ✓ One Sky
- ✓ Development In Nigeria
- ✓ CRADLE, Calabar
- ✓ Richard Ingwe, University of Calabar, Nigeria

They graciously provided support and assistance in the field work as well as made available relevant results of their previous studies to aid this research.

The Canadian Energy Technology Centre provided free of charge the RETscreen software that was used to estimate the cost of the mini hydro scheme, as well as other relevant materials

My family has been very supportive- my mum, Mrs A O Fasunloro, my brother, Lola, my sister, Tola and my MH, Oluwabunmi.

My colleagues in the University and on the EGTL project have also been very wonderful.

To all, I say a heart felt thank you!

Dedication

This dissertation is dedicated to:

The All Seeing

The All Knowing

The All in All

The All Sufficient

The Almighty God

The source of all knowledge!

Abbreviations

ADB	African Development Bank
DIN	Development in Nigeria
ECN	Energy Commission of Nigeria
FGN	Federal Government of Nigeria
GDP	Gross Domestic Product
HP	Hydro Power
IEA	International Energy Agency
IPP	Independent Power Projects
IRR	Internal Rate of Return
KW	Kilo watt
LCOE	Levelised Cost of Energy
MG	Mega watt
MHP	Mini Hydro Power
NEPA	National Electric Power Authority
NDA	Niger Dams Authority
NPV	Net Present Value
NREP	National Rural Electrification Program
NWU	North West University
OCR	Obudu Cattle Ranch
PHCN	Power Holding Company, Nigeria
PPP	Public Private Partnerships
PWD	Public Works Department
RE	Renewable energy
REMP	Renewable Energy Master Plan
SA	South Africa
SHP	Small Hydro Power
TLCC	Total Life Cycle Costing
US	United States of America
WBS	Work Breakdown Structure
WEC	World Energy Council
WSSD	World Summit on Sustainable Development

Key words

- Base load generation sources
- Econometric model
- Energy availability
- Hydro Power
- Internal Rate of Return
- Levelised Cost of Energy
- Net Present Value
- Renewable energy
- Remote, off-grid areas
- Small Hydro Power
- Total Life Cycle Cost

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CHAPTER ONE

Introduction

1.0 Overview of Nigeria

Nigeria is the most populous country in Africa, with a population in excess of 140 million according to the 2006 national census figures. It occupies a total land area of 932,770km^2 (World Bank Report 2007). About 70% of the total population live in the rural areas, while 30% live in urban centres. The capital city is Abuja, with a population of 1.4 million (2006 census). There are 36 states, each with its own capital. Lagos is the commercial nerve center of the country and accounts for up to 50% of all commercial activities that takes place in the country.

Figure 1: Map of the Federal Republic of Nigeria

Source: (www.mapsofworld.com 2007)

The country accounts for about 20% of the global black population, in other words, one in every five black persons is a Nigerian! Further, it accounts for 47 percent of West Africa's population and 41 percent of the region's GDP (World Bank Report 2007), and its population is made up of about 200 ethnic groups, 500 indigenous languages, and three major religions, Islam, Christianity and traditional religions. The largest ethnic groups are the Hausa-Fulani in the North, the Igbo in the Southeast, and the Yoruba in the Southwest.

1.1 Energy situation (Historical Perspectives)

The first generating plant was built in Lagos in 1898 by the colonial government and was managed by the Public Works Department (PWD). In 1950, the federal government established the Electricity Corporation of Nigeria (ECN) through the instrument of ordinance No. 15. It was vested with the responsibility of running the generating station. Subsequently in 1962 the Niger Dam Authority (NDA) was established to build dams. However, the first large scale hydro power station in Nigeria was built in Kainji on the River Niger with an installed capacity of 760MW and with expansion to 1,150MW in 1968, followed by Jebba in 1984 and Shiroro in 1990 with installed capacities of 570MW and 600MW respectively.

Electricity supply in the country has been through centralized generating station (hydro and thermal) with high capacities (above 100MW). The major operator in the sector is the National Electric Power Authority (NEPA), now the Power Holdings Company of Nigeria (PHCN), which was created after the merger of the then Electricity Corporation of Nigeria (ECN) and the Niger Dams Authority by Decree No. 24 of 1972. The demand for electricity is shared between residential, industrial and commercial consumers in the proportion 50:25:25 (National Energy Policy, 2003). About 2% to 5% of the capacity of the national grid is contributed by the private sector –Independent Power Projects (Okoro et al, 2004). These private producers sell power to PHCN for transmission and distribution to consumers, while the other balance of power demand in the country is being supplied by private generating sets (Zarma 2006). Total installed electricity generation capacity is presently assessed at 5.9 GW, and about a third of this is actually available on the grid.

Despite the fact that the energy industry is over 100 years old in the country, efficient provision of reliable electricity has remained elusive, especially since the oil boom years of the 1970s. In fact, in recent years, the problems in the sector have reached crisis proportion. National electricity power system collapse has become prominent and power supply has become increasingly erratic. Further, there is an inadequate coverage in terms of geographical spread. Only about 40% of the population are connected to the national grid.

In response to these challenges, many businesses and households have resorted to self provision, often at high costs and environmental pollution. For example, one study of 179 Nigerian manufacturers by Lee and Anas (1996) revealed that 92 percent of firms surveyed owned electricity generators. Considering that the situation had grown much worse since 1996 when the study was carried out, it is most obvious that the percentage would have increased. Substantial self-provision is also the norm for many low-income consumers. In fact, it is estimated in the National Energy Policy (NEP 2003), published by the government, that self generation measures by various industries and other consumers is at least 50% of the total installed capacity of the national grid.

1.2 Previous Initiatives at addressing the power challenge

In appreciation of the critical role of electricity to national development, successive governments have over the years experimented with a number of initiatives aimed at addressing the energy challenge. Notably, in the early 80's, the National Rural Electrification Program was introduced, with the aim of connecting all the country's local government headquarters and some important urban towns to the national grid. Several millions of dollars was spent and presently, about 600 out of the 774 local governments in the country have been connected to the grid, **but the approach has been targeted more at the demand side of the energy equation (distribution), without a commensurate investment in the supply side (generation).** In essence, this program did not record the expected success in spite of all the good intentions of the government and the huge investment that went into it.

The government commenced a process of implementing a comprehensive reform of the energy sector in 2004. This stemmed from its appreciation of the fact that, for a permanent solution to the problem, a holistic approach which will cover all the facets of the energy industry is the right path. The key highlight includes a hybrid approach of encouraging public and private partnership in power generation, as well as a review of the policies and laws governing the sector. This is aimed at making these policies less bureaucratic and more responsive to the challenges associated with the sector, and it is expected to open the country to more foreign direct investment in the energy industry. Further, a review of the tariff structure is also envisaged with a view to making the industry more lucrative for investors. It is noteworthy that Nigeria currently has one of the lowest electricity tariffs in the world, with a cap of N6/kWh; this is less than 4 South Africa cents.

As an immediate and stop gap measure to improve the situation, there was a projection to increase the installed capacity from 5.9GW to 10GW before the end of 2007 through the construction and commissioning of a number of power stations. To this end, the Federal government alone has spent a total sum of US$ 7.5 billion to meet this projection (Obasanjo, 2008). A total of 12 new stations are being built across the country. They include:

o Geregu, Kogi State	(414 MW),
o Papalanto, Ogun State	(335MW),
o Omotosho, Ondo State	(335MW),
o Alaoji, Abia State	(310MW)
o Ikot Abasi, Akwa Ibom State	(two :188MW + 300MW),
o Sapele, Delta State	(451MW),
o Omoku, Rivers State	(230MW),
o Egbema, Imo State	(338MW),
o Ihuabor	(451MW),
o Calabar, Cross River State	(561MW)
o Gberian/Ubie	(225MW).

These projections were not met by the end of 2007 due to a number of factors such as inadequate funding, lack of adequate and realistic planning and a change in government policies due to political change in leadership.

However, in spite of the enormous investments by the government and private sector in the last couple of years, it is doubtful that the desired result will be achieved. **This is because, all the new Power Projects that are under construction in various parts of the country are designed to be natural gas powered**, with the supply expected to come from the Niger Delta region. Though, Nigeria has the seventh largest gas reserve in the world with 5 trillion cubic metres (tcm) of proven natural gas reserve, the extent of restiveness and militancy in this region in the last 5 years, characterized by pipeline vandalisation and hostage taking, makes it very doubtful that the required natural gas feed stock will always be readily available. **Furthermore, the idea of centralised generation will have very minimal effect on**

increasing the access to electricity in rural and remote locations, where it is presently a paltry 10%, as against 82% in urban areas.

Therefore, to achieve a meaningful boost in generation capacity and ensure access improvement, attention should be paid to these rural and remote areas where about 70% of the total population resides, through the development of non conventional energy sources that will be localised to serve the areas.

1.3 Problem Statement and Substantiation

From the foregoing, it becomes extremely important to investigate the potential of Renewable Energy (RE) in Nigeria, especially in remote off grid areas with a view to developing more cost effective and more environmentally friendly energy generation options.

Obudu Ranch, the foremost tourism destination in Nigeria which is located in a typical remote location and has the potential to contribute to the nation's tourism industry has been chosen for the case study research. Presently, electricity is being supplied to the ranch through the use of diesel powered generating sets, costing about R1.5m annually in running expenses. The adjoining communities are currently without electricity, although a few of the residents have acquired generators to enable them generate energy mostly for their domestic use. Aside the high cost associated with this, the discharge of noxious contaminants into the atmosphere is also undesirable.

Therefore, this research work investigated the potential of RE sources in reducing the cost of generating electricity at the ranch, as well as the provision of energy for the surrounding communities that are presently without electricity. Its potential in minimising the adverse environmental impacts associated with the use of diesel powered generating sets was also appraised.

Further, the work established a framework for a systematic and scientific evaluation process for making well informed RE decisions and trade-offs, using technological, environmental and economic considerations.

1.4 Research Objectives

The objectives of this research work include:

1. Identification of the RE sources available at the case study location.
2. Evaluation of these sources to establish the preferred option, using relevant techno economic and environmental considerations.
3. Investigation of the potential of this preferred RE source towards addressing the high cost of electricity generation by the ranch
4. Investigation of the potential of this preferred RE source towards addressing the adverse environmental impact of the status quo.
5. Investigation of the potential of RE to also provide source of electricity for the surrounding communities which are presently without it.
6. Making beneficial recommendations to relevant stakeholders, drawing from the research findings.

1.5 State of Renewable Energy in Nigeria

The primary governmental agency for the development and promotion of RE technologies in the country is the Energy Commission of Nigeria (ECN), which is under the Presidency. It was established in 1981 and its mandate includes strategic energy planning, policy co-ordination, and performance monitoring for the entire energy sector. It is also charged with the responsibility of laying down guidelines on the utilization of energy types for specific purposes and developing recommendations on the exploitation of new sources of energy. RE is therefore a component of its mandate and it has a number of pilot demonstration programs developed as promotional activities (Iloeje, 2002) as presented in Table 1 below.

Table 1: Promotional pilot schemes (ECN)

Technology	Applications	Capacity Range	No
Solar-PV	Village Electrification Village TV Health Center Power Water Pumping Telecommunication	0.88 – 7.2kWp	11
Wind Generator	Village Lighting	5kW	1
Solar Dryer	Rice and Forage Dry	1.5 – 2 tonnes	4
Biodigester	Production of Biogas using cow dung, pig waste, chicken droppings, cassava peelings, human waste	$10 - 30m^3$	6
Hot Water Heater	Hospital Hot Water	800 liters	1
Improved Woodstoves	Community Promotion Projects for Cooking	80 – 200 persons per day	
Chick Brooder	Chick Brooding	100 – 200 Birds	7

1.6 Obudu Cattle Ranch (OCR)

Obudu is a town of about 20,000 people in South-South Nigeria. The town, just north of Cross River state, is surrounded by mountains and about ten per cent of Nigeria's tropical rainforest. It hosts the Obudu ranch, which is reputed as one of the foremost tourists' destination on the continent of Africa.

This ranch provides a suitable area for studying and demonstrating the robustness of RE for resolving energy crisis. In spite of its high profile status as one of Africa's foremost tourism resort for the elites and international tourists, its location on a plateau summit of between 1,500 to 1,750 metres above sea level, within a very challenging terrain, makes it difficult to connect the resort to national electricity grid. For example, the road linking the nearby towns to the ranch has as much as 22 sharp bends; including one that bends so dangerously that it earned the soubriquet 'devil's elbow'. The road stretches through 11 long kilometres and rises to a peak of about 1,575 metres above sea level.

Since the grid electrical cables mostly follow existing roads, the connection of the ranch to the grid would present serious physical, environmental and financial challenges. The complicated engineering processes that will be associated with the difficult terrain would significantly increase the cost of connection as well as result in its exposure to the unreliable public power supply system.

1.7 Research Approach

In this work, the energy demand in OCR and the adjoining communities was estimated based on a socio-economic survey carried out by Development in Nigeria (DIN), an NGO in Calabar, the state capital of Cross River where the Ranch is located.

Further, a survey of the area was done in liaison with other relevant NGOs. Secondary data from previous work and literature were sourced and studied. Interviews were conducted with relevant experts to identify the numerous RE sources in the case study location. They were then traded off against some relevant evaluation criteria to arrive at the most realistic source for powering the resort and its adjoining communities.

Thereafter, a comparative analysis of this selected source was carried out against the status quo- diesel powered generating sets, to establish their techno economic attributes.

1.8 Overview of dissertation

In the chapters that follow, the concepts, processes of analyses and results, as well as the recommendations and conclusions of this research work are presented.

Chapter two reviews relevant literature and the findings of previous research efforts. It underscores the progress that had been made so far, and gave direction for a new and unique approach to the research area.

Chapter three is concerned with the investigation of the existing sources of Renewable Energy in the case study location. During a visit to Obudu, some secondary data were gathered from a number of NGOs that had earlier done useful ground work in the location. In addition, a survey of literature and interviews with some experts were explored.

In chapter four a trade-off was carried out between the numerous RE sources identified in Chapter 3. A number of evaluation parameters were developed and the trade-off was done against these parameters to establish the RE option most suited towards meeting the project objectives.

Chapter five presents a comprehensive techno economic analysis of the selected RE option in the preceding chapter against the status quo at the ranch, a diesel powered generating set. A number of economic evaluation measures as well as technological analysis were employed to compare the attributes of the two options and establish the preferred one in terms of techno economic and environmental considerations.

Chapter 6 compares the results obtained in Chapter 5 with some established standards and benchmarks by notable experts and international agencies as a basis for validation of research findings and results.

Finally, chapter seven concludes the research work with recommendations and conclusions.

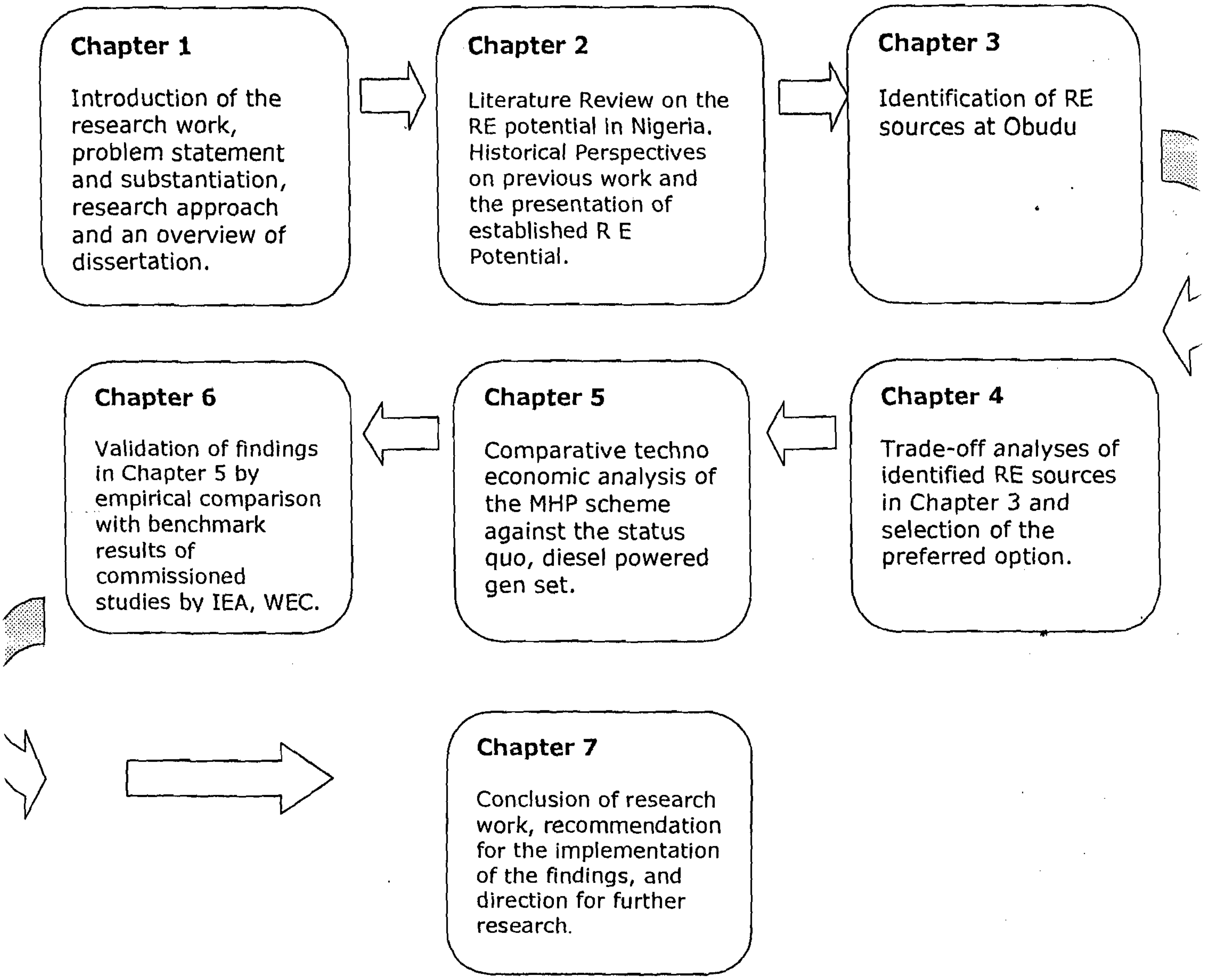

Figure 2: Chapters division and contents overview

CHAPTER TWO

Literature Review

Preamble

In the previous chapter, the enormity of the energy challenge confronting Nigeria was introduced, with a particular emphasis on the case study location, Obudu. This has set the tone for a survey of relevant literature, sourced from previous work done in the research area; publications of relevant agencies, organisations and energy experts to document the present state of research in the area of interest. This will underscore the progress that has been made so far, as well as provide direction for a new and unique angle to the quest for evolving a solution to the energy challenge confronting Obudu ranch, which can then be replicated in other remote locations of comparable terrains and situations.

2.1 Historical Perspectives

The history of electricity in Nigeria dates back to 1896 when electricity was first produced in Lagos, fifteen years after its introduction in England (Okoro et al, 2002). The total capacity of the generators used then was 60KW. In other words, the maximum demand in 1896 was less than 60KW. In 1946, the government electricity undertaking was established under the jurisdiction of the public works department to take over the responsibility of electricity supply in Lagos state.

In 1950, a central body was established by the legislative council which transferred electricity supply and development responsibilities to the care of the central body known as the Electricity Corporation of Nigeria (ECN). Other bodies like the Native Authorities and Nigerian Electricity Supply Company had licenses to produce electricity in some locations in Nigeria. There was another body known as Niger Dams Authority (NDA) established by an act of parliament. The Authority was responsible for the construction and maintenance of dams and other work on the River Niger and elsewhere, generating electricity by means of hydro power, improving navigation, and promoting fish brines and irrigation (Okoro et all, 2002).The energy produced by NDA was sold to ECN for distribution and sales at utility voltages.

On April 1st 1972, the operation of ECN and NDA were merged in a new organization known as National Electric Power Authority (NEPA). Since ECN was mainly responsible for distribution and sales, and NDA was created to build and run generating stations and transmission lines, it was felt that their operations could be harmonised. The primary reasons adduced for merging the organizations were:

- "It would result in the vesting of the production and the distribution of electricity power supply throughout the country in one organization which will assume responsibility for the financial obligations".
- "The integration of the ECN and NDA should result in the more effective utilization of the human, financial and other resources available to the electricity supply industry throughout the country".

(Niger Power Review, 1989)

Renewable Energy has been talked about for more than thirty years while fossil fuels have increased in use and declined in supply. While some gains have been made, the world is currently being challenged to make the switch to renewable energy in time, to avoid significant environmental and climatic changes. At the World Summit on Sustainable Development (WSSD), held in Johannesburg in 2002, energy was one of the most contentious issues. Setting targets for new renewable energy (defined as modern biomass, solar, wind, small-scale hydro, geothermal and wave) as well as reducing perverse and harmful energy subsidies were hotly debated.

RE sources are universally acknowledged to present cost-effective alternatives for providing energy to remote and rural areas in developing countries, according to IEA (Ackom, 2005). Over the last two decades, they have been increasingly promoted as a way to reduce the oil dependency of importing countries, to reduce adverse environmental impacts (both local and global) of energy production, and to provide modern forms of energy in remote areas.

Moreover, utilizing local and distributed renewable energy, as opposed to the somewhat centralised system, which is insufficient for the national electricity demand, will strengthen the energy security of Nigeria.

The government of Nigeria, in realisation of the potential of RE, also commissioned a team of experts to develop a National Policy on RE development and its application. The key elements in the policy on the development are as follows (Iloeje, 2002):

• To develop, promote and harness the Renewable Energy (RE) resources of the country and incorporate all viable ones into the national energy mix.

• To promote decentralized energy supply, especially in rural areas, based on RE resources.

• To de-emphasize and discourage the use of wood as fuel.

• To promote efficient methods in the use biomass.

• To keep abreast of international developments in RE technologies and applications.

2.2 Renewable Energy Potential in Nigeria

2.2.1 Small Hydro Power Potential

Nigeria's hydro potential is high and currently accounts for about 32% of the total installed commercial electricity capacity. The overall large scale potential (exploitable) is in excess of 11,000MW (Zarma, 2006) out of which only 19% is currently being tapped or developed.

Aliyu and Elegba (1990) are of the opinion that, from the definitions and classifications of various hydro schemes provided in Table 2, the small, mini and micro hydro schemes hereafter referred to as small scale, are of specific interest for the task of meeting part of the energy requirements of some rural communities in the country.

Table 2: **Classification of various Hydro Schemes (Aliyu and Elegba, 1990)**

Scale of Hydro Scheme	Capacity Range (MW)
Large	> 100
Medium	50-100
Intermediate	10-50
Small	1-10
Mini	0.5-1
Micro	< 0.5

There are considerable hydro potential sources from the numerous large rivers, small rivers, streams and the various river basins that had been developed over the years. Rivers are distributed all over the country and constitute potential sites for hydro power schemes which can serve the urban, rural and isolated communities. An estimation of Rivers Kaduna, Benue and Cross River (at Shiroro, Makurdi and Ikom respectively) indicated that total capacity of about 4,650MW is available (ECN, 2002), while the estimate for the River Mambillla plateau is put at 2,330MW (Makoju, 2003).

A large number of untapped hydro power potential sites identified by Motor Columbus (1970) are presented in **Table 3** below

Table 3: Potential Hydro Power Sites in Nigeria (Motor Columbus, 1970)

Location	River	Average discharge (m3/s)	Max Head	Potential Capacity (MW)
Donko	Niger	1650	17	225
Jebba	Niger	1767	27.1	500
Zungeru II	Kaduna	343	97.5	450
Zungeru I	Kaduna	343	100.6	500
Shiroro	Kaduna	294	95	300
Zurubu	Kaduna	55	40	20
Gwaram	Jamaare	75	50	30
Izom	Gurara	55	30	10
Gudi	Mada	41.5	100	40
Kafanchan	Kongum	2.2	100	5
Kurra II	Sanga	5.5	430	25
Kurra I	Sanga	5	290	15
Richa II	Daffo	4	480	25
Richa I	Mosari	6.5	400	36
Mistakuku	Kurra	2	670	20
Kombo	Gongola	128	37	35
Kiri	Gongola	154	30.5	40
Kramti	Kam	80	100	115
Beli	Taraba	266	79.2	240
Garin Dali	Taraba	323	36.6	135
Sarkin	Suntai	20	180	46
Danko	Donga	45	200	130
Gembu	Katsina Ala	170	45	30
Kasimbila	Katsina ala	740	49	260
Katsina Ala	Benue	3185	25.9	600
Makurdi	Niger	6253	31.4	1950
Lokoja	Niger	6635	15.25	750
Onitsha	Osse	80	50	30
Ifon	Cross River	759	47	400
Ikom	Cross River	1621	15.5	180
Afikpo	Cross River	1704	10	180

Recent studies have shown that large hydro power potential sites are distributed in 12 States and in the river basins (Esan 2003). However, small hydro power potential sites exist in virtually all parts of Nigeria. Further, Esan reported that there are about 278 unexploited sites with total potentials of 734.3MW. So far, about eight small hydro power stations, with an aggregate capacity of 37MW have been installed in the country by both the private sector and the government as shown in **Table 4**.

Table 4: Existing Small Hydro Schemes in Nigeria (Esan, 2003)

S/No.	River	State	Installed Capacity (MW)
1	Bagel (I)	Plateau	1
	(II)		2
2	Kurra	Plateau	8
3	Lere (I)	Plateau	4
	(II)		4
4	*Bakalori	Sokoto	3
5	*Tiga	Kano	6
6	*Oyan	Ogun	9

*No longer functional

It is instructive that the 8MW station at Kurra fall, which was developed by a private company (NESCO), has been in existence for close to 80 years.

2.2.2 Wind Energy Potential

Globally, Nigeria is situated within low to moderate wind energy zone. Ojosu and Salawu (1989) carried out the most comprehensive nationwide study on wind energy availability and potential in the country. The study used data on wind speeds and directions for 22 meteorological stations from the Nigerian meteorological office, Oshodi near Lagos. The meteorological data are based on the 3-hourly records of wind from 1951 to 1983, a period of 22 years.

The isovents at 10m heights were drawn and four different wind zones were identified. The energy potential for wind energy utilization in Nigeria is broadly appraised by Ojosu and Salawu (1990) as shown in **Table 5** below:

Table 5: Potential of Windmill Utilization according to end use (Ojosu and Salawu, 1990)

S/No	Area	Small-scale Irrigation	Domestic water supply	Livestock Water Supply	Electric Power Supply
1	Semi-Arid, Hot dry areas: Sokoto, Kano Katsina, and Borno States	GP	GP	GP	GP
2	Along the shores of Lake Chad	GP	GP	GP	GP
3	Temperate Areas: Plateau, Nigeria, Bauchi and Gongola	GP	GP	GP	GP
4	Savannah, warm Humid areas: Kwara, Benue and Gongola States	LP	MP	MP	LP
5	Along the shores Rivers Niger and Benue	LP	MP	LP	LP
6	Hot humid areas: Oyo, Ogun, Ondo, Bendel, Anambra, Imo, Cross River States	LP	MP	LP	LP
7	Coastal Areas" Lagos, Rivers, Akwa Ibom parts of Bendel and Ondo States	LP/MP	LP/MP	LP/MP	LP/GP
8	All other Areas	-	-	-	GP
9	Off shore				

Key
GP **Good Potential**
MP **Medium Potential**
LP **Low Potential**

They further estimated the maximum energy obtainable from a 25m diameter wind turbine with an efficiency of 30% at 25m height to be about 97 mWh/yr for Sokoto, a site in the high wind speed regions; 50 mWh/yr for Kano; 25.7 mWh/yr for Lagos and 24.5 mWh/yr for Port Harcourt.

2.2.3 Solar Energy Resources in Nigeria

According to Bala et al (2000), Nigeria is endowed with an average daily sunshine duration of 6.25 hours, ranging from 3.5 hours at the coastal areas and 9.0 hours at the far northern boundary. Similarly, it has an annual average daily solar irradiation of about 5.25 $kW/m^2/day$, ranging from 3.5 $kW/m^2/day$ at the coastal area to $7.0 kW/m^2/day$ at the northern boundary. The nation receives about 4.851×10^{12} kWh of energy per day from the sun. This is equivalent to about 1.082 million tonnes of oil equivalent (mtoe) per day; and about 4 thousand times the current daily crude oil production. It is also equivalent to about 13 thousand times the daily natural gas production figure Bala et al (2000). This huge energy resource from the sun is available for only about 26% of the day.

The country also experiences some cold and dusty atmosphere during the harmattan, in its northern part. This usually last for about four months (November-February) annually, (Garba et al, 2002). The dust has an attenuating effect on the solar radiation intensity (Bala, et al, 2001)

Based on the land area of $924 \times 10^3 km^2$ for the country and an average of 5.535 $kWh/m^2/day$, Nigeria has an average of 1.804×10^{15} kWh of incident solar energy annually. This value is about 27 times the nation's total conventional energy resources in energy units, and it is over 117,000 times the amount of electric power generated in the country in 2002 (Garba et al, 2002).

In other words, only about 3.7% of the national land mass is needed in order to annually derive from the sun an amount of energy equal to the nation's conventional energy reserve.

2.2.4 Biomass

The biomass resources of Nigeria are identified as wood, forage grasses, shrubs, and animal wastes. Other sources are the waste from forestry, agricultural, municipal and industrial activities, as well as aquatic biomass. The biomass potential of the country has been estimated to be about 8×10^2 mJ (Esan, 2003).

Further, Esan reported that plant biomass could be utilised as fuel for small-scale industries. It could also be fermented by anaerobic bacteria to produce a very versatile and cheap fuel gas – biogas.

2.3 Other Resources

Presently, the potential of other resources like geothermal, waves, tidal and ocean still remain largely unquantified (Garba and Bashir, 2005).

CHAPTER THREE

Renewable Energy Sources in Obudu

Preamble

In the previous chapter, a review of literature was carried out to apprise the existing body of knowledge concerning the research interest. In this chapter, the renewable energy sources in the case study location would be presented. This is based on the data and information gathered during a visit to the location, as well as secondary data from previous field work carried out by some NGOs with interest in the area.

3.1 Overview

In establishing the techno-economic potential of renewable energy sources in successfully addressing the energy needs and requirements of the Obudu Cattle Ranch and the adjoining communities, a trip was made to the case study location in December 2007. Fortunately, a number of Non Governmental Organisations (NGOs), notably the Development in Nigeria, and CRADLE, both based in Calabar, the state capital, have undertaken numerous research work on the energy requirements of the community using a variety of research methods like direct interviews, observations, experts' views etc. Some very relevant data were sourced from these NGOs.

Similarly, **One Sky, the Canadian Institute for Sustainable Living, BC, Ontario,** had just recently commissioned a $1.46 million research study into the potential of RE in some communities in the state, and Obudu was included. The work involved 5 Nigerian NGOs, 5 Canadian groups, 16 communities, many community-based organizations, 3 state ministries and 4 One Sky interns. Fortunately, a copy of the report of the study was obtained and it has clearly identified some RE sources in the community. Drawing on some relevant secondary data from these various work, consultations with NGOs, statistical data from corporate bodies, government ministries and agencies as well as some further literature survey, the RE sources in the location were identified and presented as follows:

3.2 Renewable Energy sources at Obudu

3.2.1 Mini Hydro Power Potential

Based on the secondary data collected, a geo-demographic analysis was employed to study the stream density at the Obudu ranch plateau by CRADLE in 2005 . The small hydro power potential of the plateau was evaluated. The speed of the four streams flowing from one of the several mountain ranges and joining to form confluences with the bigger Afundu stream hydrological basin located (6° 22.29 N to 6°23.16N and 9°22.40E to 9°21.55E), close to the ranch resort were measured using the float method (Richard Ingwe, 2005).

The process involved the establishment, at each of the four confluence stations, of two survey points (10 metres apart) downstream, for conducting five consecutive flow measurements. The streams' heads were also measured using a Meridian series of Magellan Global Positioning Systems hand-held set . Overall, two hydrological surveys were undertaken: the first involved random surveys of some streams, including Egaga Waterfall (with a gross head of 1,224 feet -considered a useful potential for the installation of small hydro water) around the entire plateau. The second survey carried out concentrated on one specific hydrological basin (Afundu stream) in order to facilitate a more accurate prediction of the magnitude of energy that is derivable from the stream.

The speed of stream flow (in cubic metres per second) of the various stations surveyed northwards from Egaga Waterfall were: 15m^3/s, 14.6 m^3/s, 12.8 m^3/s, and 18.4 m^3/s. The widths of the survey stations, also northwards from Egaga fall were measured to be: 10.30m, 8.2m, 10m, and 6.70m (CRADLE, 2005). The four streams surveyed were just a few selected from a wide range of streams flowing from the mountain peak into the selected hydrological basin. In addition, a number of other distinct hydrological basins that are yet unmapped exist at the Obudu ranch plateau (Richard Ingwe, 2005)..

Based on these findings, the small hydro power potential of the region could be described as good for RE installation. The Egaga waterfall (with a gross head of about 1,224 feet) is considered a particularly good location for a potential mini hydro scheme.

3.2.2 Biomass Potential

The potential of bio-energy at the ranch would be discussed under two broad types of biologically derived energy source that could be harnessed at the Obudu ranch plateau. These include:

- ✓ biomass (i.e. phytomass and zoo mass) and
- ✓ bio-fuel or liquid bio-energy.

Biomass energy potential for electricity generation could be achieved by installing biogas plants that will undertake the bio-digestion of bio-waste within a methane reactor. There are various biomass resources in existence at the location and they constitute a good potential for biogas plant installation at the resort. Some of these sources are:

- ✓ The enormous quantity of cow dung from an estimated 13,000 strong herds of white Fulani cattle grazing the region and managed by the Nomadic Fulani herdsmen within the various plateau mountain ranges.
- ✓ Additional dung is produced by about 500 of the exotic species of the Holstein-Friesian.
- ✓ Large quantities of food remnants and wastes from the catering service of the Protea Hotels, the South African company currently managing the resort.
- ✓ Agricultural wastes from nearby forest and vegetal matters such as the Guatemala grass. The Ranch plateau's land size of about 400 square kilometres is covered by various forest vegetation zones (bracken scrub, Grassland and Guatemala grass) from which biomass could be generated for feeding a biogas plant.
- ✓ Special trees which grow rapidly as well as efficient energy plants could be planted to ensure that the acceptable ecological standard is maintained.

The bio-energy potential of the ranch could be better appreciated when it is considered that in Germany, biogas plants have successfully been installed to use dung from only 900 pigs.

3.2.3 Solar Energy Potential

A major advantage of solar energy in Obudu plateau is that its temperate type climate (a maximum temperature of less than 25° C all year round) is suitable for high performance of solar modules, compared with other hotter parts of Nigeria. Other good factors for determining the solar potential of the Obudu Plateau include the Mean Monthly Global Solar Radiation, measured in kilowatt hours/m^2/day.

CRADLE (2004) obtained the following result during a field work: "3.6kWh/m^2/day in January, rising to about 5.36kWh/m^2/day in March, dropping steadily to the lowest point in July when it rises for the second time within the year to about 4.26kWh/m^2/day in October. After this it drops to about 46kWh/m^2/day in December"

The low temperature at the plateau also meets the need for solar thermal technologies for water and space heating.

3.2.4 Wind Energy Potential

The wind energy potential is considered not realistic for power generation, based on the current level of available wind turbine technologies. Wind turbines generally require wind speed of between 3.5m/sto 4.5 m/s to generate electricity. However, the wind speed at the Ranch is seldom ever higher than 3m/s. This establishes that wind energy is currently not a feasible source for electricity generation in the case study location.

CHAPTER FOUR

Trade-off Analyses of RE sources

Preamble

The preceding chapter identified the numerous RE sources in existence at the case study location. In this chapter, these numerous sources will be traded off against some evaluation parameters to establish the most suited option for achieving the project objective. The trade-off will follow a methodical evaluation procedure with techno economic and environmental considerations. This will ensure that the source with the most promising potential for addressing the energy challenge at Obudu is selected.

4.0 Trade-off analyses

Based on the results from the field study, it is obvious that there are three probable candidate sources of renewable energy that can be deployed to address the power challenge of the communities. They are presented as follows:

- Mini hydro power
- Biomass
- Solar energy

These three options are analysed against the under listed number of evaluation parameters to establish there suitability towards achieving the project objectives.

1 Economic competitiveness
2 Technical characteristics
3 Availability of expertise for operation and maintenance
4 Environmental impact of technology

4.1 Economic competitiveness

This can be further sub divided into two:

- Initial cost of installation
- Operating & Maintenance cost

Initial installation cost: This refers to the total initial capital outlay required for the design and installation of the RE source as well as the preparation of the surroundings and environment for the project.

Operating and Maintenance Cost: This refers to the total recurrent expenses incurred in the course of the active functional life of the project. It involves the cost of operating it as well that needed to keep it reliably operational through regular maintenance.

The World Energy Council has established some global benchmarks for the cost of electricity for the various generation technologies, and it is presented in **Table 6** below.

Table 6: Cost of electricity for various technologies

	Present cost of electricity	**Potential future cost**
Wind	4–8 ¢/kWh	3–10 ¢/kWh
Solar thermal	**12–34 ¢/kWh**	**4–20 ¢/kWh**
Large hydropower	2–10 ¢/kWh	2–10 ¢/kWh
Small hydropower	**2–12 ¢/kWh**	**2–10 ¢/kWh**
Geothermal	2–10 ¢/kWh	1–8 ¢/kWh
Biomass	**3–12 ¢/kWh**	**4–10 ¢/kWh**
Coal (comparison)	4 ¢/kWh	
Heat		
Geothermal heat	0.5–5 ¢/kWh	0.5–5 ¢/kWh
Biomass — heat	1–6 ¢/kWh	1–5 ¢/kWh
Low temp solar heat	2–25 ¢/kWh	2–10 ¢/kWh

All costs are in US$-cent per kilowatt-hour.

Source: World Energy Assessment, 2004 update

4.2 Technical Characteristics

This criterion refers to the evaluation of the simplicity and effectiveness of the technology during both the installation phase, and the operation and maintenance stages. The desired technology should have a simple functional design, easy to operate and maintain. An evaluation of the different options with reference to this characteristic is as presented below.

4.2.1 Mini hydro power:

Hydro power is derived from the potential energy available from water due to the height difference between its storage level and the tail water to which it is discharged. Power is generated by mechanical conversion of the energy into electricity through a turbine, at a usually high efficiency rate. Depending on the volume of water discharged and height of fall (or head), hydropower can be large or small.

There is currently no international consensus on the delineation of small hydropower (REMP), however, the most popular categorisation divides small hydro into

- Small hydro (1-5MW)
- Mini hydro (<1MW)
- Micro hydro (<100KW).

Thus, the consideration of 0.75 MW capacity makes the scheme a mini hydro case.

4.2.1.1 Overview of Technology

A relatively simple technology, it depends on the availability of water flow or discharge and a drop in level over the river course. For the run-of-the-river scheme, where there is no impoundment, computation of the hydropower only requires a determination of the magnitude of the discharge and the head or vertical distance of the waterfall. The flow can be measured by the bucket method, which simply determines the time taken to fill a bucket of a known volume. Discharge can also be determined by the velocity method, where a weighted float is timed over a longitudinal flow path, and stream depths are measured across the flow section to determine the cross-sectional area. Where the topography permits the hydro yield is firmed up by the construction of a small dam which creates a reservoir. The storage provides additional head and flow regulation, thereby increasing power output and extending power generation over low-flow periods.

Other components of the small hydro include the penstock, a turbine which transforms the energy of flowing water into rotational energy, an alternator which converts rotational energy into electricity, a regulator which controls the generators, and wiring which delivers the electricity to the end users. In many systems, an inverter is incorporated to convert the resulting low-voltage direct current (DC) into 220 or 240 volts alternating current (AC) compatible with existing national power systems (International Energy Agency, 2002).

Sometimes excess power is stored in batteries for use during periods of low flow or water scarcity. The bulk of small-hydro requirements and accessories are presently import-based.

4.2.2 Solar Energy:

The two broad classifications of Solar Energy technologies are Solar Thermal Energy technologies and Solar Photovoltaic (PV) technologies.

Solar systems use lenses or mirrors combined with tracking systems to refract and focus heat from the sun on some fluid which is boiled to power a steam turbine, which is then used to generate electricity. The primary mechanisms for concentrating sunlight are the

- Parabolic trough,
- solar power tower and
- Parabolic dish.

The high temperatures produced by solar systems can also be used to provide heat and steam for a variety of applications (cogeneration). The technologies require direct sunlight (insolation) to function, and are of limited use in locations with significant cloud cover.

The technology is applicable for both central and distributed electricity generation, and possesses the highest potential for competing with conventional power plants after wind power plants (REMP). All concentrating systems possess four key elements:

- Concentrator
- receiver,
- transport-storage unit, and
- power conversion unit.

The power conversion unit has successfully employed Rankine, Brayton, Combined or Stirling cycles.

4.2.2.1 The parabolic trough system or solar farm

This system consists of long parallel rows of identical concentrator modules, typically using trough-shaped glass mirrors. The trough concentrates the direct solar radiation onto an absorber pipe located along its focal axis as it tracks the sun from east to west. The heat transfer medium, typically oil, at temperatures up to 400°C, is circulated through the pipes.

The hot oil then converts water to steam through a heat exchanger, to drive a steam turbine in a typical Rankine cycle conversion system.

These types of systems have been deployed for use in Southern California grid, involving 9 solar thermal plants, ranging from 14 to 80 mW in capacity. They have a combined accumulated operating year experience of 100 plant years and have been feeding over 9 billion kWh of electricity into the Southern California grid, generating over US$ 1 billion.

4.2.2.2 The solar central receiver or power tower

In this system, the solar central receiver or power tower is surrounded by a large array of dual-axis tracking mirrors (heliostats), reflecting direct solar radiation onto a fixed receiver located at the top of the tower. Within the receiver, a fluid - water, liquid metal, and molten salt have been used - transfers the absorbed solar heat to the power conversion system where it is used to produce steam in a steam generator. Advanced high-temperature power tower concepts are currently being investigated, in which air is heated above 1000°C in order to feed it into the conventional gas turbine of modern combined cycles.

4.2.2.3 The parabolic dish

The parabolic dish solar power plant technology consists of a number of parabolic dishes which focus the solar radiation onto an engine to heat and expand an enclosed amount of gas (hydrogen). The engine operates on the Stirling cycle thermodynamics principle. It is claimed by the manufacturer to be well suited to supply peaking power to a grid, it is capable of running at night on any common fuel natural gas, landfill gas, propane, diesel, fuel oil, and gasoline.

4.2.3 Biomass:

4.2.3.1 Overview of Biogas and Bio-fuels Technologies

The techniques used for the conversion of organic biomass materials to solid, liquid and gaseous fuels have been in existence for many years in both the developed and developing countries.

4.2.3.2 Biomass Technology

Biogas is a mixture of 60 to 70% methane (CH_4), 23 to 38% carbon dioxide (CO_2), about 2% hydrogen (H_2) and traces of hydrogen sulphide (H_2S). It is produced by the anaerobic (i.e. in the absence of oxygen) digestion (fermentation) of organic materials and its lower heating value is approximately 6kWh/m^3 (International Energy Agency, 2002). Biogas can be used in the household for heating, cooking and lighting; in the community farm; for agricultural and industrial production.

4.2.3.3 Biomass Cogeneration Technologies

Cogeneration (Combined Heat and Power or CHP generation) is a fully mature, proven, competitive and environmentally benign technology. Such claims arise from its relatively much higher efficiency and its ability to use wastes effectively, whether such waste is biomass, municipal or industrial. It is applicable as a distributed power generation source in applications that require both heat energy and electrical power. Cogeneration is the simultaneous production of electrical power and heat energy in applications where both are used preferably on the generation site, or excess of either is sold to a third party such as the utility grid (for excess electricity) or a district heating or cooling systems (for excess heat energy). In conventional power plants on the other hand, up to 70% of the thermal energy used for production of electricity is lost in cooling towers or in condensers cooled by river, lake or sea water. In general, application of cogeneration is based on the heat energy demand of the system (International Energy Agency, 2002).

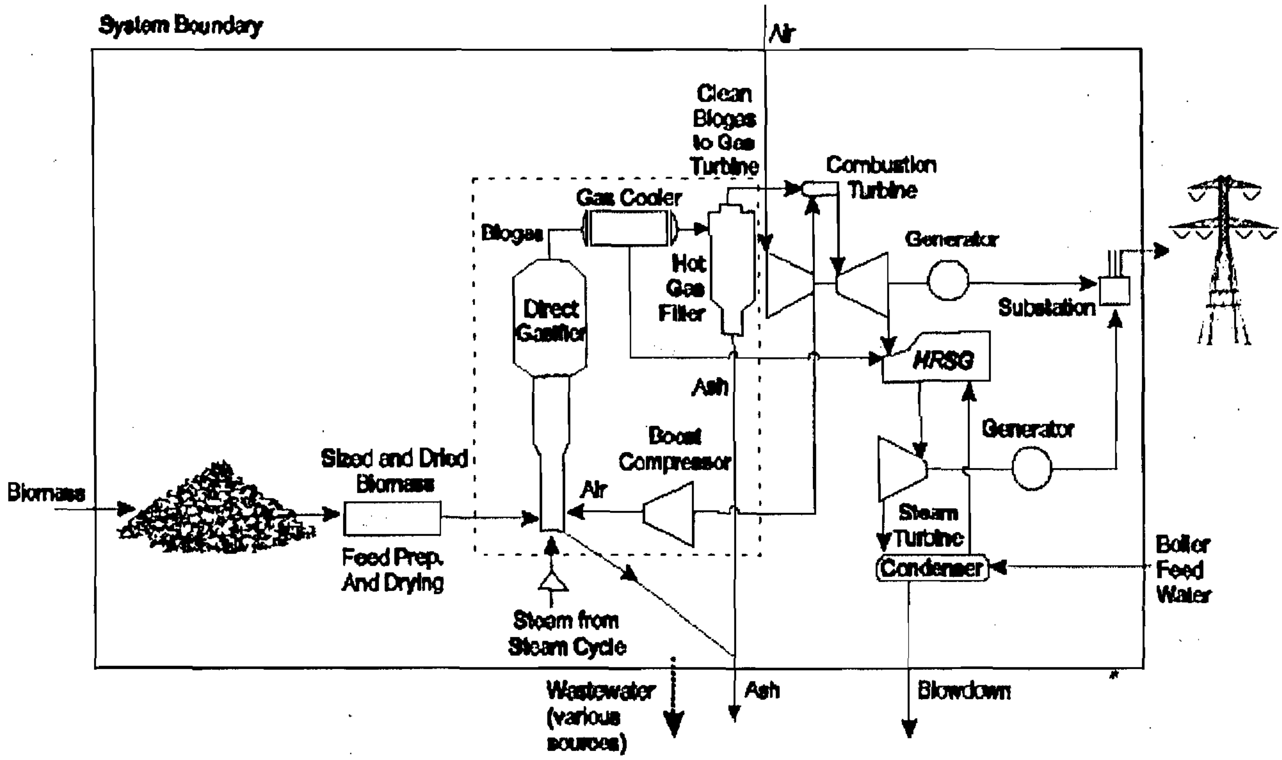

Figure 3: Biomass Integrated Gasification Combined-Cycle System Schematic

Source: Electric Power Research Institute and U.S. Department of Energy, Renewable Energy Technology Characterization

4.3 Environmental impact of technology

Considerable attention has been justifiably placed on the environmental impacts of all human activities over the past couple of decades. This underscores the concern for the continuous preservation and sustainability of our environment. An evaluation of the environmental impact of the three RE options under consideration is presented below.

4.3.1 Small hydro power:

They are generally environmentally friendly and non polluting. They do not involve deforestation, rehabilitation and submergence. However, depending on the site and layout of the scheme, trees may have to be uprooted. In general, the ecological impact of small-scale hydro is minimal.

4.3.2 Solar energy:

Solar technologies are also environmentally friendly and non polluting. The ecological impact is also very minimal and it poses no significant danger on the ecology of the surrounding

4.3.3 Biomass:

Biomass technologies provide a great thermal efficiency and carbon emissions reduction advantages over conventional power plant technologies. In fact, it is a carbon reducing technology. More so, it has been identified as a significant measure that can be used to meet the Kyoto Protocol CO_2 targets of several EU countries.

4.4 Availability of local expertise for operation

This is also a key evaluation parameter, considering the fact that the technology eventually chosen will need to be run and maintained by skilled hands, preferably from the location area. This will have the effect of bringing down the cost of labour, as well as give a feeling of part ownership and sense of responsibilities to the communities. A key factor to use for this is the existence of the technology around the country. If the technology has been in use in the country, then, it is most obvious some experienced hands must have worked and acquired the needed expertise. In this regard, mini hydro power gets the edge. It has been widely deployed in Nigeria for about 80 years and its use has been well established.

4.5 Matrix for evaluation criteria

A matrix for these evaluation criteria is presented below.

Table 7: Matrix for evaluation criteria

RE Technology	Economic competitiveness	Technical characteristics	Operation expertise	Environmental impact	Rating
Small hydro	4	6	6	4	20
Solar	2	4	4	4	14
Biomass	4	4	2	6	18

Key

2 Poor

4 Fair

6 Good

The matrix clearly show that mini hydro power is the RE source most suited to meeting the project objective of addressing the energy challenge of the Obudu Cattle Ranch and its adjoining communities, based of the key evaluation criteria employed.

CHAPTER FIVE

Comparative techno economic analysis of small hydro power scheme and diesel powered generating set.

Preamble

In the previous chapters, a comprehensive study was undertaken to identify the renewable energy sources in existence at the case study location, and a subsequent analysis has established small hydro power energy as the most suited source for meeting the energy requirements of the ranch and the adjoining communities. In this chapter, a comparative techno economic analysis of this chosen source will be undertaken against the status quo, a diesel powered generating set which is presently being utilised for electricity generation. This will establish the techno economic edges of the mini hydropower renewable energy over the status quo.

5.1 Diesel powered generating sets

5.1.1 Techno Analysis

Diesel Engine ignition systems, such as the diesel engine and Homogenous Charge Compression Ignition engines (HCCI), rely solely on heat and pressure created by the engine in its compression process for ignition. Diesel engines take in air, and shortly before peak compression, a small quantity of diesel fuel is sprayed into the cylinder via a fuel injector that allows the fuel to instantly ignite. Most diesel engines also have battery and charging systems as secondary auxiliary components; added by manufacturers as luxury for ease of starting, turning fuel on and off (which can also be done via a switch or mechanical apparatus), and for running auxiliary electrical components and accessories. Most new engines, however, rely on electrical systems that also control the combustion process to increase efficiency and reduce emissions.

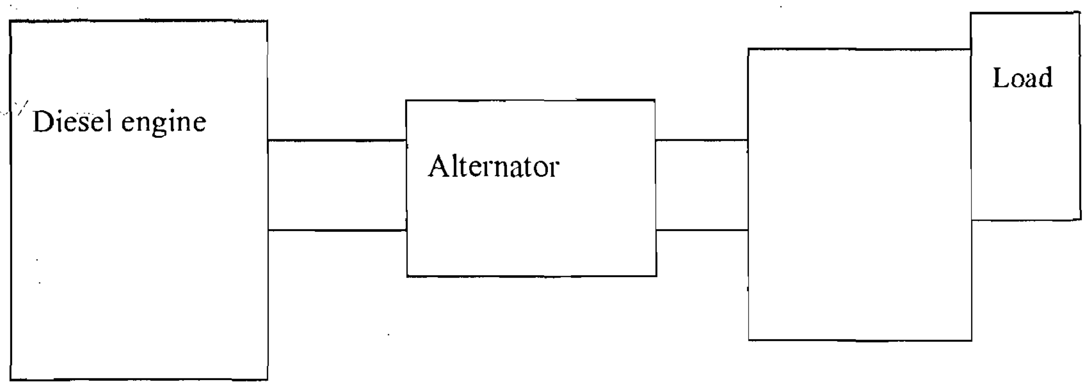

Figure 4: **Schematic diagram of the conventional diesel power plant**

5.1.2 Diesel Engine Efficiency

Diesel engines, like all other internal combustion engines are primarily heat engines and as such, thermodynamic cycles are used to describe the phenomenon that limits its efficiency. None of these cycles exceed the limit defined by the Carnot cycle which states that the overall efficiency is dictated by the difference between the lower and upper operating temperatures of the engine. An engine is usually fundamentally limited by the upper thermal stability of the material used to make it. All metals and alloys eventually melt or decompose; however, there is significant research into ceramic materials that can be made with higher thermal stabilities and desirable structural properties. Higher thermal stability can permit greater temperature difference between the lower and upper operating temperatures and thus greater thermodynamic efficiency.

The thermodynamic limits assume ideal operating conditions but the real operating environment is substantially more complex and all the complexities reduce efficiency. In addition real engines run best at specific loads and rates as described by their power curve. Most steel engines have a thermodynamic limit of at most 37%. Even when aided with turbochargers and stock efficiency aids, most engines retain an *average* efficiency of about 20% (RETScreen, 2005).

5.1.3 Environmental impact of technology

Internal combustion engines, particularly reciprocating internal combustion engines, produce air pollution emissions, due to incomplete combustion of carbonaceous fuel. The main derivatives of the process are carbon dioxide (CO_2), water and some soot, also called particulate matter (PM). The effects of inhaling particulate matter have been widely studied in humans and animals and include asthma, lung cancer, cardiovascular issues, and premature death. There are however some additional products of the combustion process that includes nitrogen oxides and sulphur and some incombustible hydrocarbons, depending on the operating conditions and the fuel/air ratio (Ogunleye, 2007).

The fuel does not get completely burned in the engine and passes through the exhaust unchanged. The primary causes of this are the need to operate near the stoichiometric ratio for gasoline engines in order to achieve combustion (the fuel would burn more completely in excess air) and the "quench" of the flame by the relatively cool cylinder walls. Increasing the amount of air in the engine reduces the amount of the first two pollutants but tends to encourage the oxygen and nitrogen in the air to combine to produce Nitrogen Oxides (NO_x), demonstrated to be hazardous to both plant and animal health. Further chemicals released are Benzene and 1, 3-Butadiene that are particularly harmful. Not all the fuel burns up completely, so Carbon Monoxide (CO) is also produced.

Carbon fuels contain sulphur and impurities, leading to sulphur oxides (SO_x) and Sulphur Dioxide (SO_2) in the exhaust, promoting acid rain. One final element in exhaust pollution is Ozone (O_3). This is not emitted directly but made in the air by the action of sunlight on other pollutants to form 'ground level Ozone', which, unlike the 'Ozone Layer' in the high atmosphere, is regarded as bad, if levels are too high. Ozone is actually broken down by Nitrogen Oxides, so one tends to be lower where the other is higher (Ogunleye, 2007).

Haralambopoulos and Spilanis (1997) gave the pollutant emission factors necessary for the calculation of the emissions from a diesel powered electricity producing plant as shown in row 1 of table 8. From the load estimation, the community requires about 3000kkWh presently, dividing this value by 1000 and multiplying the result with the emission factors for diesel oil gives the values in row 2 of table 4 which gives the emission per day of the pollutants for one plant. Row 3 of tables 4 gives the emission per year of the pollutants of one plant. It is noticeable that the values in row 3 of table 4 can be obtained by multiplying in the values in row 2 of tables 4 with 365 the number of days in a year.

Table 8: The emission per annum of pollutants by a diesel plant

Emission	Pollutants in kilogram			
	NOx	CO_2	SO_2	Particulates
Emission factor for diesel(kg/1000kWh)	1.5	1062.5	19.4	1
Emission per day of the pollutants from a diesel plant	4.5	3187.5	58.2	3
Emission per annum of the pollutants from a diesel plant	1642.5	1163438	21243	1095

5.2 Mini Hydro Power (MHP) Scheme

5.2.1 Techno analysis

The objective of a hydro power scheme is to convert the potential energy of a mass of water flowing in a stream, with a certain fall to the turbine head, into electric energy at the lower end of the scheme where the powerhouse is located. The power output from the scheme is proportional to the flow and to the head.

COMPONENTS OF A HYDRO SYSTEM

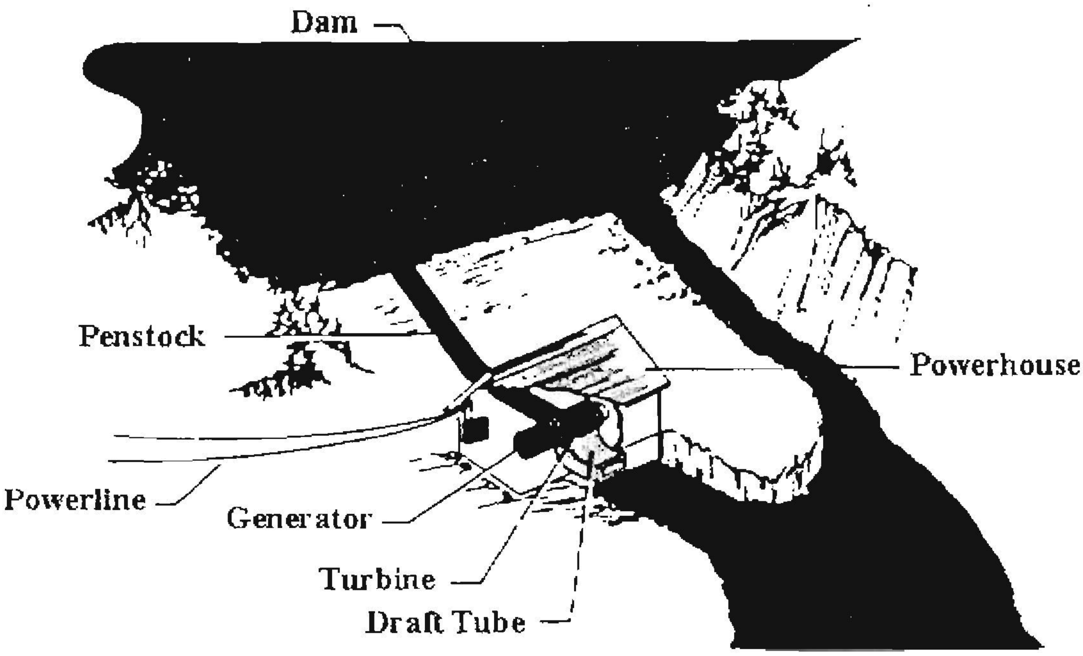

Figure 5: Adapted from RETscreen's small hydropower project analysis manual

Schemes are generally classified according to the head:

- High head: 100-m and above
- Medium head: 30 - 100 m
- Low head: 2 - 30 m

Considering the result of our field studies which showed a head of 1224 ft, the scheme can be categorised as high head.
Schemes can also be defined as:-

- Run-of-river schemes
- Water storage developments

Run-of-river schemes

Run-of-river refers to a mode of operation in which the hydro plant uses only the water that is available in the natural flow of the river. It implies that there is no water storage and that power fluctuates with the stream flow. Medium and high head schemes use weirs to divert water to the intake; it is then conveyed to the turbines via a pressure pipe or penstock. Penstocks are expensive and consequently this design is usually uneconomic. An alternative is to convey the water by a low-slope canal, running alongside the river to the pressure intake or fore bay and then in a short penstock to the turbines. If the topography and morphology of the terrain does not permit the easy layout of a canal, a low pressure pipe, can be an economical option. At the outlet of the turbines, the water is discharged to the river via a tailrace (RETscreen, 2005).

Water storage (reservoir) developments

For a hydroelectric plant to provide power on demand, either to meet a fluctuating load or to provide peak power, water must be stored in one or more reservoirs. Unless a natural lake can be tapped, providing storage usually requires the construction of a dam or dams and the creation of new lakes. This impacts the local environment in both negative and positive ways, although the scale of development often magnifies the negative impacts. This often presents a conflict, as larger hydro projects are attractive because they can provide "stored" power during peak demand periods. Due to the economies of scale and the complex approval process, storage schemes tend to be relatively large in size (RETscreen, 2005).

5.2.2 Components of the small hydro power scheme

A mini hydro power scheme has two distinct components:

- Civil works component.
- Electrical and mechanical components.

Civil works

The main civil works of a small hydro development are the diversion dam or weir, the water passages and the powerhouse. The diversion dam or weir directs the water into a canal, tunnel, penstock or turbine inlet. The water then passes through the turbine, spinning it with enough force to create electricity in a generator. Civil works components of a project are related more to the local topography and physical nature of a site.

Electrical and mechanical components

The primary electrical and mechanical components of a small hydro plant are the turbines and generators. Turbines used for small hydro applications are scaled-down versions of turbines used in conventional large hydro developments. The ones used for low to medium head applications are usually of the reaction type and include Francis and fixed and variable pitch (Kaplan) propeller turbines. The runner or turbine "wheel" of a reaction turbine is completely submersed in water.

However, for high-head applications, impulse turbines are employed. Impulse turbines include the Pelton, Turgo and cross flow designs. The runner of an impulse turbine spins in the air and is driven by a high-speed jet of water.

There are two basic types of generators used in small hydro plants - synchronous or induction (asynchronous).

A synchronous generator can be operated in isolation while an induction generator must normally be operated in conjunction with other generators.

5.3 Environmental impact of Hydro scheme technology

The EIA commissioned a team of experts in 2000 to extensively study the environmental impact of the technology in comparison with other renewable energy sources using the Life Cycle Analysis approach. The report concluded that very minimal environmental impacts are experienced. However, it must still be noted that stream water will be diverted away from a portion of the stream and this can cause some dislocation to the aquatic life in the stream. The highest possible impact noted is the noise from the turbines during operation, electromagnetic radiation and obstruction of the transmission lines. This could be reduced by selecting less noisy turbines, locating the power house far from residential area and the transmission lines far from pathways and roads to reduce the frequency of exposure of people to the transmission lines.

5.4 Economic analysis of the technology

Overview of the selected software

The RETscreen software was developed by Canada's Energy Technology Centre, in collaboration with UNEP, NASA, GEF, and the World Bank along with a network of 221 experts from industry, government and academia. It now has users in 213 countries and is recognized as the world's leading software for screening the viability of clean energy technology applications. Survey of literature has further confirmed its extensive use by decision makers and energy experts around the World. Further, the small hydro power unit of the IEA in its published review of the software estimated that to date, stakeholders have saved about $600 million worldwide through the use of the RETScreen software, databases and related training material. As of April 2008, more than 100,000 people in 220 countries are estimated to be using RETScreen, and the number of people benefiting from this decision-support and capacity-building tool is reported to be growing at more than 600 new users every week (RETscreen, 2005).

5.4.1 Mini hydro scheme

Using the RETscreen software, the estimated cost of the Obudu small hydro scheme was calculated and the result is presented below.

Country	**Nigeria**			
Cold climate	yes/no	No	0	
Design flow	m^3/s	0.002	0	
Gross head	m	300	0	
Number of turbines	turbine	2	Kaplan	
Type		Francis		
Flow per turbine	m^3/s	0		
Turbine runner diameter per unit	m	0.02	Micro	
Facility type		Small		
Existing dam	yes/no	No		
New dam crest length	m			
Rock at dam site	yes/no	No	0.00%	
Maximum hydraulic losses	%	10.00%		
Miscellaneous losses	%	10.00%		
Road construction				
Length	km	4		
Tote road only	yes/no	Yes		
Difficulty of terrain		2		
Tunnel				
Length	m	4		
Allowable tunnel headloss factor	%	4.00%		
Percent length of tunnel that is lined	%	15%		
Diameter	m	2.4		
Canal				
Length in rock	m	100		
Terrain side slope in rock (average)	°	10		
Length in impervious soil	m	100		
Terrain side slope in soil (average)	°	10		

Total canal headloss	m	0.2		
Penstock				
Length	m	200		
Number	penstock	1		
Allowable penstock headloss factor	%	3.00%		
Diameter	m	0.05		
Average pipe wall thickness	mm	6.02		
Distance to borrow pits	km	5		
Transmission line			Central-grid	
Grid type		Off-grid		
Length	km	4		
Difficulty of terrain		2		
Voltage	kV	25		
			Amount	
	Amount	**Adjustment factor**	**$**	
Initial costs (credits)	**$**		*15 600*	***Relative costs***
Feasibility study	13 000	1.2	18 000	2.90%
Development	15 000	1.2	14 800	3.30%
Engineering	11 000	1.35		2.70%
Power system			10 000	
Hydro turbine	10 000	1	104 000	1.80%
Road construction	104 000	1	334 400	19.20%
Transmission line	209 000	1.6	0	61.80%
Substation	0			0.00%
Balance of system & miscellaneous			14 000	
Penstock	14 000	1	0	2.60%
Canal	0		10 000	0.00%
Tunnel	10 000	1	20 000	1.80%
Other	20 000	1	44 000	3.70%
Sub-total:	44 000		$40 800	
Total initial costs	**406 000**			

Assumptions for the RETScreen cost analysis were developed on due consultation with some experts with broad experience and professional judgement. The following primary assumptions were employed:

- A transmission line will be no more than 4.0 kilometers long; and will carry 25KV;
- Hydraulic losses were put at 5%
- Miscellaneous losses were also put at 5%

- Adjustment factors were factored into the estimates to account for costing differences.

Thus, the total amount required for the design and development of the scheme is estimated by the software to be $540,800 US (R4,056,000).

The O&M cost is estimated to be about 5% per annum of the initial cost. This gives $23,920 US.(R179,400)

5.4.1.1 Expected Output Profile

Considering the nature of the resort and the type of business they engage in, it is obviously necessary that there is a 24/7/365 provision of electricity. In other words, there is a zero tolerance for outages except for routine maintenance duration. Thus for the analysis of the revenue profile we will be employing uninterruptible power availability.

This gives the total desired hour of availability per annum to be

Total hour = 24 x 365 = 8760 hour / annum

This can be used to calculate the total output from the turbine, using a capacity factor of 0.8

Total power output = Turbine capacity x load factor

= 750 x 0.8

= 600KW.

Thus, total energy output = 600 x 8760

= 5,256,000 kWh/ annum

Thus the estimated total energy output is 5,256,000kWh.

= 5,256 mWh

An expansion coefficient of 1.38 over the present level of demand was factored into the design because of the numerous expansion projects been undertaking at the Ranch, which are at various stages of completion. Based on the present estimated yearly demand of about 3250 mWh, there will be an excess generation of 2006 mWh, part of which will be taken up as soon as these projects are completed. Further, the state government is also at an advanced stage in the establishment of a number of agro based industries in the location. Projected energy requirement for these industries were not made available, thus making estimation a bit difficult. However, a number of assumptions were made based on prevailing economic indicators and statistics like GDP, inflation rate, discount rate etc in the country as presented in the Assumption section below.

5.4.1.2 Key assumptions/ facts

1. *The selling price of electricity has just recently being increased from the previously subsidised N6/kWh (R0.4/kWh) to N10/kWh (R0.66/kWh) as part of the measures of the deregulation of the industry. Thus, the new price is used for the analysis*
2. *The estimated increase in demand is put at twice the GDP growth of the country over the next five years because of the numerous ongoing projects. GDP for 2007 was 6.3%.*
3. *The cost of selling energy /kWh is kept constant at N10/kWh, which is consistent with the system in Nigeria where government is responsible for fixing the price. The previous price of N6/kWh was kept constant for about five years before the recent increase.*
4. *The exchange rate between the numerous currencies under consideration as at the day of analysis are as shown below:*

1 US Dollar	=	*120 Nigerian Naira*
1 South African Rand	=	*15 Nigerian Naira*
1 South African Rand	=	*7.5 US Dollar*

5. *The rate of increment in the O&M expenses was estimated by finding the average inflation rate over the last 5 years and using it as the incremental factor per annum. (12%)*
6. *Insurance cost was estimated at 2% of the initial investment cost, and a 12% increment factor per annum*
7. *A discount rate of 12% was used for the analysis*
8. *A corporate tax rate of 30% is used for the analysis, this is consistent with the rate in Nigeria*

9 *A tax holiday period of 2 years is factored into the analysis. This is consistent with the system in Nigeria for new investment in the Power sector*

10 *Depreciation was calculated using the double declining method over the estimated 40 years service life of the technology.*

5.4.2 Levelised Cost of Energy for the mini hydro scheme

Empirical survey has revealed that the economics of the two schemes can be better compared using the Levelised cost of Energy (LCOE) approach, considering that the energy industry in

Nigeria is presently government regulated. The IEA (2005), defined LCOE as: 'the ratio of total lifetime expenses versus total expected outputs, expressed in terms of the present value equivalent'

The Net Present Value which is defined as the value in the base year (usually the present) of all cash flows associated with a project will be calculated and the result will be used to deduce the Total Life Cycle Cost (TLCC), from which the LCOE will be evaluated.

5.4.2.1 Estimated output/ annual revenue inflow

Table 9: Estimate of output/ annual revenue inflow

	Estimated demand (kWh)	Estimated selling price /kWh	Estimated annual revenue accrual (N)	Estimated annual revenue accrual (R)
Year 1	3250000	10	32500000	2166667
Year 2	3659500	10	36595000	2439667
Year 3	4120597	10	41205970	2747065
Year 4	4639792	10	46397920	3093195
Year 5	5224406	10	52244060	3482937

5.4.2.2 Full financial Profile of the mini hydro scheme

Table 10: Full financial Profile of the mini hydro scheme (Rands)

		Once off	Year 1	Year 2	Year 3	Year 4	Year 5
a	Initial investment	4056000					
b	O&M		156000	163800	171990	180590	189619
c	Fuelling cost		0	0	0	0	0
d	Cost of Insurance		62400	65520	68796	72236	75848
e	Depreciation expense		202800	192660	183027	173876	165182
f	Total expenses (a)once off, (b+c+d+e)yrs	4056000	421200	421980	1310970	1491873	1637017
g	Total revenue		2166667	2439667	2747065	3093195	3482937
h	Total revenue-total expenses (taxable) (i-h)		1745467	2017687	1436095	1601322	1845920
i	Tax (30%)				430829	480397	553776
j	After tax income (j-k)		1745467	2017687	1005267	1120925	1292144

Using the financial profiles above, the LCOE will be calculated in terms of the Net Present Value and the Total Life Cycle Cost.

5.4.2.3 Net Present Value for the MHP scheme

The NPV is calculated using the model below

$$NPV = \sum_{n=0}^{N} \left[F_n / (1+d)^n \right]$$

Where NPV = net present value

F_n = net cash flow in year n

N = analysis period

d = annual discount rate.

The result is presented below:

Table 11: Net Present Value for the MHP scheme (Rands)

		After tax cash flow					
		Year 1	Year 2	Year 3	Year 4	Year 5	
Total initial investment	4056000						
After tax cash flow		1745467	2017687	1005267	1120925	1292144	
Present value		1558453	1608488	715529	712368	733197	5328035
Total							

NPV = -4056000 + 5328035

= R1, 272,035

On the face value, the positive sign indicates the investment as economic.

5.4.2.4 TLCC Analysis for the MHP scheme

The TLCC (Total Life Cycle Cost) is calculated in terms of the NPV using the model below and the result is as presented below:

$$TLCC = I + \sum_{n=0}^{N} [O\&M / (1+d)^n]$$

Where I = Initial investment

O&M = Operation and Maintenance cost (no fuelling cost)

d = Annual discount rate.

Table 12: TLCC for the MHP scheme (Rands)

		Year 1	Year 2	Year 3	Year 4	Year 5	
Total initial investment	4056000						4056000
Total O&M cost		156000	163800	171990	180590	189619	
Discounted O&M cost		139286	130580	122419	114768	107595	614648
TLCC							4670648

Therefore, the TLCC is R4, 670,648

5.4.2.5 Levelised Cost of Energy for the MHP scheme

Drawing from the previous result for the TLCC, we can proceed to find the LCOE using the model below:

$$LCOE = TLCC / [Q_n / (1+d)^n]$$

Where TLCC = Total Life Cycle Cost

Qn = Quantity of output in year n

d = annual discount rate

The result is presented below:

Table 13: Levelised Cost of Energy for the MHP scheme (Rands)

	Year 1	Year 2	Year 3	Year 4	Year 5	
Estimated output	3250000	3659500	4120597	4639792	5224406	
Discounted output	2901786	2917331	2932960	2948672	2964468	14665217
TLCC						4670648
LCOE						0.32

This shows that it cost R0.32 to generate 1kWh of electricity over the first five years of operation of the plant. It is noteworthy that the prevailing selling price per kWh in Nigeria is R0.66. This makes the investment economical. The tax holiday of 2 years, which is an incentive to attract investment into the energy sector, has obviously contributed a lot to this relatively low cost of generation.

5.4.2.6 Internal Rate of Return for the MHP scheme

The internal rate of return (IRR) is a capital budgeting metric used as an indicator of the efficiency of an investment, as opposed to net present value (NPV), which indicates value or magnitude.

It is the annualized effective compounded return rate which can be earned on the invested capital, i.e., the yield on the investment.

The IRR for the mini hydro scheme was calculated using the model below:

$$NPV = 0 = \sum_{n=0}^{N} \left[F_n / (1+d)^n \right]$$

Where NPV = net present value of the capital investment

F_n = Cash flow received at time n

d = rate that equates the present value of positive and negative cash flows when used as a discount rate

An iterative equation solver was used to solve the IRR for the mini hydro scheme as follows

$$\text{nsolve}\left(-4056000+\frac{1745467}{1+d}+\frac{2017687}{(1+d)^2}+\frac{1005267}{(1+d)^3}+\frac{1120925}{(1+d)^4}+\frac{1292144}{(1+d)^5}=0,\{d\}\right)$$

and the result is approximately **25.38%.**

5.5 Economic analysis of the Diesel Powered Generator

As stated earlier, the Ranch is presently dependent on self provision of electricity through the use of 2 x 750 kVA diesel powered generators. As much as two drums of diesel are used daily to run the generators. The prevailing cost of diesel per litre in Nigeria is about N110 (7 Rands). This costs about N44, 000.00 (2,940 Rands) daily, amounting to about N308, 000 (R20,533) weekly, and a whopping N16m (R1,066,666) annually. The cost of carrying out routine maintenance and operators manning is estimated at about 5% of the total initial investment cost annually because of the frequency of use. In addition to this prohibitive cost of fuelling and maintaining the gen sets, the unquantifiable contamination of the naturally clean environment by the noxious effluent gases is also of very serious concern.

It is noteworthy that the price of diesel in Nigeria is inconsistent with the prevailing global trend due largely to the regime of fuel subsidy in Nigeria, however, with the inclination of the present government to a full deregulation of the oil sector, coupled with the rising cost of oil in the world market, it is apparent that the present cost is not sustainable. It is most likely going to increase, thus driving up the cost of electricity generation using the diesel powered gen set even further.

More so, the International Energy Agency has just recently increased its forecast for 2008 daily global oil demand. It now expects daily global oil demand to increase by 2.1 million barrels to 87.8 million barrels, or an increase of 210,000 barrels per day from the agency's's previous estimate. This increase in demand portends the reality of continuous increase in oil price over the immediate future.

Furthermore, empirical investigation has revealed that the generators have an average working life of 8 years, and the cost of a 750 kkVA gen set is presently quoted at about $150,000 US (R1,125,000) by the manufacturers. The installation cost is estimated at 10% of this cost.

5.5.1 Key facts/Assumptions

1 *The exchange rate between the numerous currencies under consideration as at the day of analysis are as shown below:*

1 US Dollar	=	*120 Nigerian Naira*
1 South African Rand	=	*15 Nigerian Naira*
1 South African Rand	=	*7.5 US Dollar*

2. *Empirical survey has shown that the average service life of a generator is about 8 years (Okoro et al, 2004).*
3. *The rate of increment in the O&M expenses was estimated by finding the average inflation rate over the last 5 years and using it as the incremental factor per annum. (12%)*
4. *The rate of increment on the fuelling cost was estimated by finding the average inflation rate over the last 5 years and using it as the incremental factor per annum. (12%)*
5. *Insurance cost was estimated at 2% of the initial investment cost, and a 12% increment factor per annum*
6. *Corporate tax of 30% is applicable, with a tax holiday for the first 2 years*
7. *Transmission infrastructure is estimated at 160% of the initial cost (RETscreen, 2005).*

5.5.2 Expected revenue accrual from the gen set

It is noteworthy that the generator is owned and used exclusively by the resort to meet its energy needs. Its capacity is oversized for the present energy requirement, though there are a lot of ongoing expansion projects which will obviously increase the demand over the immediate future. So, as it stands today, the generator only serves the resort, and the excess is not being sold to the over 20,000 people living in the sorrounding areas.

The Levelised Cost of Energy model will be used to estimate what it presently cost the resort to generate a unit of energy (kWh). This will form the basis for comparison with the mini hydro scheme. It will be assumed that the excess capacity is available for sale to other users, to standardise the basis for the comparison, and it will be taken up to the same extent as the mini hydro scheme. Moreso, since the capacity of the genset and the the mini hydro are the same, with proximal capacity factor, we can also assume that the output from them are the same. This means the cash inflow estimate for mini hydro can be used here. The cash outflow will be the real 'point of departure', and it is the direct driver of the LCOE.

5.5.3 LCOE for the Gen set

5.5.3.1 Revenue inflow profile for the Gen set

Table 14: Revenue profile for the Gen set

	Estimated demand (kWh)	Estimated selling price /kWh	Estimated annual revenue accrual (N)	Estimated annual revenue accrual R)
Year 1	3250000	10	32500000	2166667
Year 2	3659500	10	36595000	2439667
Year 3	4120597	10	41205970	2747065
Year 4	4639792	10	46397920	3093195
Year 5	5224406	10	52244060	3482937

5.5.3.2 Full Financial Profile for the Gen set

Table 15: Full Financial Profile for the Gen set (Rands)

		Cost in Rands					
		Once off	Year 1	Year 2	Year 3	Year 4	Year 5
a	Initial investment	1125000					
b	Installation cost	112500					
c	Transmission cost	1800000					
d	O&M		61875	69300	77616	86930	97361
e	Fuelling cost		1066666	1194666	1338026	1498589	1678420
f	Cost of Insurance		24750	27720	31046	34772	38945
g	Depreciation		309375	232031	174023	130518	97888
h	Total expenses (a+b+c) once off, (d+e+f+g)yrs	3037500	1462666	1523717	1620711	1750809	1912614
i	Total Revenue		2166667	2439667	2747065	3093195	3482937
j	Total Revenue - total expenses		704001	915950	1126354	1342386	1570323
	Tax (30%)				337906	402716	471097

5.5.3.3 Net Present Value

Using the previously stated model, the NPV was evaluated and the result is presented below

Table 16: Net Present Value Profile for the Gen Set(Rands)

		After tax cash flow					
		Year 1	Year 2	Year 3	Year 4	Year 5	Total
Total initial investment	-3037500						
After tax cash flow		704001	915950	788448	939670	1099226	
Present value		628572	730189	561202	597177	623730	3140870

NPV = -3037500 + 3140870

= R103,370

As stated earlier, the positive sign indicates it is an economic investment on the face value.

5.5.3.4 Total Life Cycle Costing

TLCC was also calculated using the model with the tabulated result below

Table 17: Total Life Cycle Costing for the Gen Set (Rands)

		Year 1	Year 2	Year 3	Year 4	Year 5	
Total initial investment	3037500						3037500
Total O&M & fuelling cost		1128541	1263966	1415642	1585519	1775781	
Discounted O&M & fuelling cost		1007626	1007626	1007626	1007626	1007626	5038130
TLCC							8075630

The total Life Cycle Cost is R8,075,630

5.5.3.5 Levelised Cost of Energy

The result of the LCOE analysis, using the previously stated model is presented below

Table 18: Levelised Cost of Energy for the Gen Set (Rands)

	Year 1	Year 2	Year 3	Year 4	Year 5	
Estimated output	3250000	3659500	4120597	4639792	5224406	
Discounted output	2901786	2917331	2932960	2948672	2964468	14665217
TLCC						8195630
LCOE	.					0.56

Therefore, the LCOE for the diesel powered gen set is R0.56/kWh

5.5.3.6 Internal Rate of Return IRR

The IRR was calculated using the earlier stated model by an iterative equation solver

$$nsolve\left(-3037500+\frac{704000}{1+d}+\frac{915950}{(1+d)^2}+\frac{788448}{(1+d)^3}+\frac{939670}{(1+d)^4}+\frac{1099226}{(1+d)^5}=0,\{d\}\right)$$

The result is approximately **13.28%**

5.6 Summary of economic analysis

Table 19: Summary of economic analysis (Rands)

Economic measure	Diesel powered Gen set	Mini hydro power
NPV	103,370	1,272,035
TLCC	8075,630	4670648
LCOE	0.56/kWh	0.32/kWh
IRR	13.28%	25.38%

5.7 Discussion of result

The series of economic analysis above establish that the NPV, which is the sum of all years' discounted after-tax cash flows for both options are positive. This indicates that the returns are attractive. However, the NPV for the mini hydro is almost 92% higher than the diesel powered genset.

The TLCC establishes that 42% more cost is incurred on the diesel powered genset, over a five year analysis period for the same value of output. This is driven largely by the huge fuelling cost associated with the option.

Further, the LCOE analysis shows it costs an average of R0.56 to generate a kWh of energy from the genset, while it cost R0.32 to achieve the same on the mini hydro scheme. This represents an increase of 43%.

Conclusively, the IRR for the hydro scheme is 25.38% which is almost double that for the diesel powered gen set (13.28%) at 92%, consistent with the value obtained for the NPV.

These analysis clearly establishes mini hydro scheme as the more economic option in addressing the energy challege of the case study location.

5.8 Risk Assessment

An assessment of the most critical service- impacting risks inherent in the mini hydro scheme is presented below:

1. The mini hydro scheme is dependent on flow of water. More so, the climatic condition in Nigeria consists of a rainy season which starts around March and ends September. The remaining period of the year is usually dry, with very minimal incidence of rainfall. Thus, the flow is higher during the rainy season, and it reduces over the course of the dry season which will affect the operation of the turbine.

2. As with all man made equipments, the hydro scheme is not immune to breakdowns, defects, failures and malfunction, and considering the type of business the ranch is involved in, there should be a zero tolerance for outages.

5.9 Mitigation Measures

1. As stated in the previous chapter, flow measurement had been carried out on the proposed river using the float method,and the flow ranges from $12m^3/s$ to $18.5m^3/s$. However, the flow is directly dependent on the volume of rainfall experienced over a particular period. Unfortunately, this volume of rainfall is directly under 'nature's call' and cannot be controlled. This informed the decision to base the design on a very low flow rate which has increased the design cost. However, there remains the risk of

prolonged drought, maybe over more than one season, during which the flow speed might be much less than the design value. The hydro scheme will thus stand the risk of being inoperational. The mitigation measure for this is to have a back-up system that is not dependent on water level or flow. This may make the case for retaining the existing diesel gen set as a back-up source. This is the most economical approach to addressing this risk because the gen sets are already in place and fully operational.

2. The same measure in 1 above also applies.

The implication of retaining the generating set as a back-up source which will only work during the highlighted emergencies is that the money that could have been made from their sale after decommissioning is lost, however, the reduction in operating cost associated with the mini hydro scheme will offset this drawback over the medium term. This is in addition to the significant reduction in environmental pollution associated with the scheme.

CHAPTER SIX

Validation of Research Findings

Preamble

In the preceding chapter, comprehensive analyses of the techno economics of the mini hydro scheme and the diesel powered gen set were carried out to compare the two options. Four different economic measures were employed, and they all establish clearly that the mini hydro scheme is a more economic option ahead of the status quo- diesel gen set. Further, the technical characteristics and the environmental effects of the two options were evaluated and it was also established that the mini hydro scheme is preferred in both regards. In this chapter, the merits of the research work shall be verified by considering some empirical works that has been done previously.

6.1 Empirical Investigation

Over the years, a number of local and international agencies have commissioned reputable experts in the energy industry to undertake extensive studies to establish global bench marks for various RE sources. The idea is basically to provide reference and guidance for all subsequent project, as well as to form a yardstick against which real projects can be measured. In Nigeria, as stated earlier in this work, the Presidency commissioned a team of experts drawn from the academia, the energy industry, the industry regulators and other relevant stakeholders to prepare a Renewable Energy Master Plan (REMP) in 2004. An aspect of the mandate given to the team was the investigation of the technological characteristics and environmental impacts of the various technologies. The final report establishes benchmarks for the various technologies. It concluded that in terms of environmental impact of technology, cost of electricity generation and technical characteristic of the technology, the mini hydro is preferred to the status quo- diesel powered gen set (REMP, 2004). The findings of this research work have also confirmed these advantages of mini hydro over the diesel powered gen set.

6.2 International Energy Agency Report

Further, the IEA also commissioned an adhoc committee of officially appointed international experts with a mandate to provide reliable information on key factors affecting the economics of electricity generation using a range of technologies. The report was meant to serve as a resource for policy makers and industry professionals seeking to better understand generation costs of these technologies.

Cost data provided by the experts were compiled and used by the joint IEA/NEA Secretariat to calculate generation costs. The data were obtained from more than 130 power plants across all regions of the world. The technologies and plant types covered by the study included units under construction or planned that could be commissioned in the respondent countries between 2010 and 2015, and for which they have developed cost estimates generally through paper studies or bids.

The calculations were based on the levelised lifetime cost approach. The calculations use generic assumptions for the main technical and economic parameters as agreed upon in the *ad hoc* group of experts, e.g., economic lifetime (40 years), average load factor for base-load plants (85%) and discount rates (5% and 10%).

The relevant portion of the executive summary is presented below, and is consistent with the result of this research work. The full executive summary report is attached as appendix a

> *Micro-hydro generating technologies*
> *"The hydro power plants considered in the study are small or very small units. At a 5% discount rate, hydroelectricity generation costs range between some 40 and 80 USD/mWh for all plants except one. At a 10% discount rate, hydroelectricity generation costs range between some 65 and 100 USD/mWh for most plants. The predominant share of investment in total levelised generation costs explains the large difference between costs at 5 and 10% discount rate"*
>
> Source: International Energy Agency 2007

6.3 World Energy Council Report

More so, in 2004, the World Energy Council also commissioned a team of experts to investigate the cost of energy generation for different Renewable Energy sources and to establish some global benchmarks for these costs, the relevant portion of the report is presented below.

Table 20: WEC global benchmark for cost of energy

	Present cost of electricity	Potential future cost
Wind	4–8 ¢/kWh	3–10 ¢/kWh
Solar thermal	12–34 ¢/kWh	4–20 ¢/kWh
Large hydropower	2–10 ¢/kWh	2–10 ¢/kWh
Small hydropower	2–12 ¢/kWh	2–10 ¢/kWh
Geothermal	2–10 ¢/kWh	1–8 ¢/kWh
Biomass	3–12 ¢/kWh	4–10 ¢/kWh
Coal (comparison)	4 ¢/kWh	
Heat		
Geothermal heat	0.5–5 ¢/kWh	0.5–5 ¢/kWh
Biomass — heat	1–6 ¢/kWh	1–5 ¢/kWh
Low temp solar heat	2–25 ¢/kWh	2–10 ¢/kWh

All costs are in US$-cent per kilowatt-hour.

Source: World Energy Assessment, 2004 update

For the small hydro, it was estimated that it cost between 2-12 US cents/kWh. The techno economic analysis in the previous chapter evaluated the LCOE for the mini hydro scheme to be 32 South African cents/kWh, which is equivalent to 2.6 US cents/kWh.

All these commissioned studies by world renowned experts and undertaken under the auspices of the foremost energy agencies on earth have established global standards. Working independently, this research work has arrived at economic figures that are consistent with the studies. This provides a convincing basis for the validation of the findings through empirical comparisons.

CHAPTER SEVEN

Conclusion and Recommendations

Preamble

In the preceding chapter, the findings of this research work were validated by empirical referencing with other studies of comparable scopes executed by experts and international agencies. In this concluding chapter, recommendations would be propounded on the way forward for the pathetic energy situation in remote locations in Nigeria, the process to be followed to arrive at the preffered RE solution for other locations with comparable RE potential, as well as the scope for further research work on the project area. The project work will thus be concluded here.

7.1 Conclusion

This research work set out to address the energy challenges confronting remote, off grid locations in Nigeria where access is presently a paltry 10%. Obudu Ranch was chosen for a case study with the intention that the result of the study could be replicated in other remote locations of comparable terrain. The community was visited in the course of the work, and data from some notable Non Governmental Organisations that had carried out base studies in the location were also employed. These studies revealed the three possible renewable energy sources that could be used to address the energy challenges as the:

- ✓ Mini hydro
- ✓ Biomass
- ✓ Solar

These options were traded off against four desired evaluation parameters, using a methodical process, and the mini hydro turned out to be the best source. The framework employed for the trade-off is presented below:

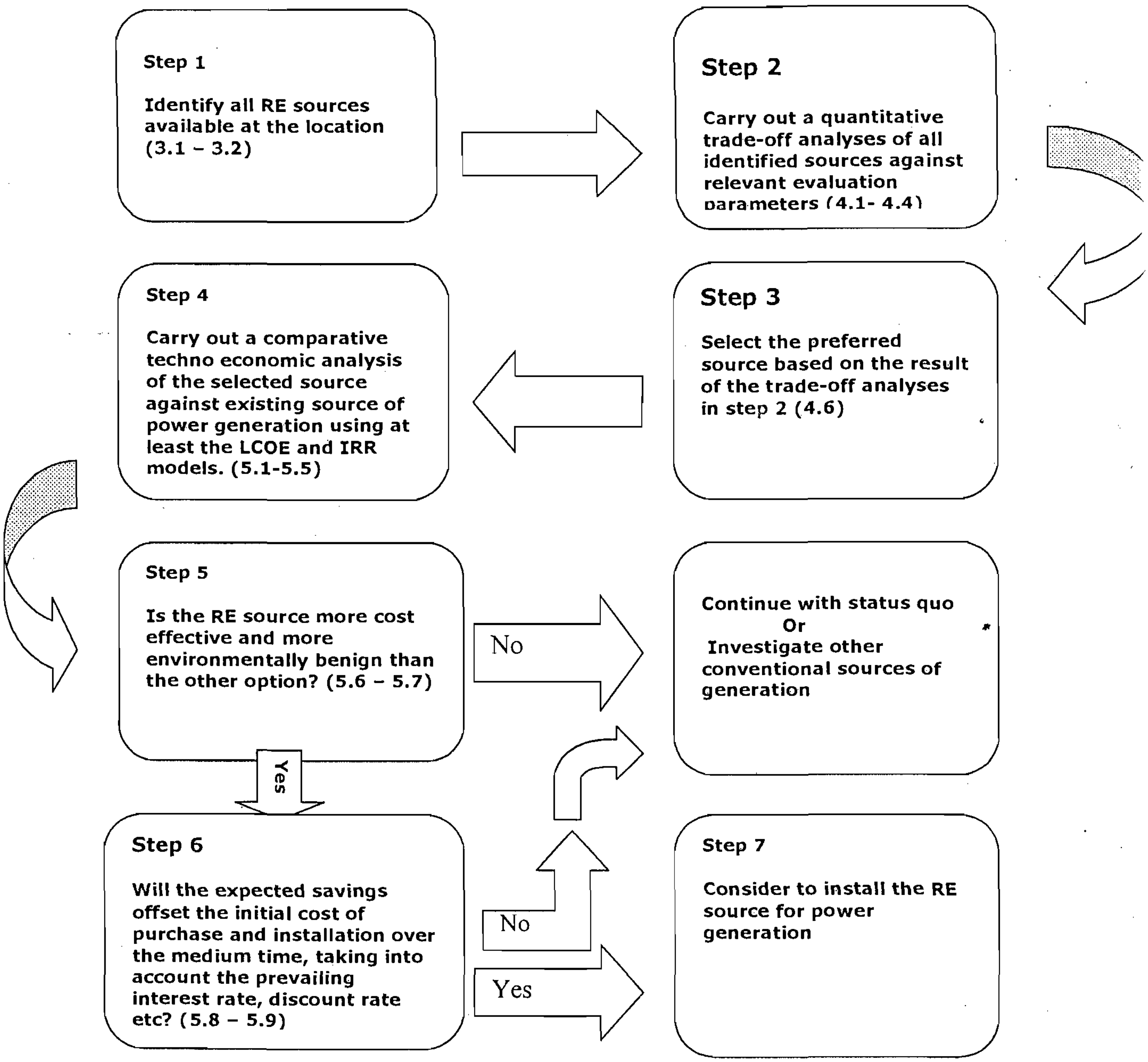

Figure 6: Flow chart for making RE decisions

The relevant paragraphs where the concepts were applied in this work are presented in brackets.

After the trade-off, a comparative techno economic analysis was carried out to appraise the potential of the mini hydro against the status quo- diesel powered gen set; and investigate the benefits of the proposed scheme over the present source. The comprehensive analysis establishes that the mini hydro scheme is a more cost effective option, offering a 42% savings in life cycle costing over the five years of analysis, and a 43% reduction in the levelised cost of energy. In addition, it is also more environmentally friendly.

Thus, the case has been made for a switch from the status quo to the mini hydro scheme.

7.2 Recommendation

Drawing from the findings, it has been proven clearly that the mini hydro scheme is more cost effective and more environmentally friendly than the status quo. Therefore, it is strongly recommended that the management of the ranch make a switch to this better option as soon as practicable.

The benefits include:

- ✓ A cleaner and purer environment for the inhabitants of the location as the option is much more environmentally friendly
- ✓ A cheaper source of electricity generation with an estimated 43% reduction in cost of generation per kWh
- ✓ More income for the government through collection of tax

It is also recommended that RE decisions in other remote locations, of comparable terrain and situation, should utilise a methodical process of evaluation and trade-offs as was done in this work. The framework is presented in paragraph 7.1 above.

This would ensure that such decisions are made from a well informed and methodical standpoint, and improve the tendency for making the right decisions in terms of techno economic and environmental considerations.

Further, the numerous state governments in Nigeria that usually spend several millions annually for connecting remote areas to the ineffective national grid are encouraged to explore RE sources in such areas to address the energy needs.

Beyond this, it is clear that renewable energy holds much promise in improving the energy situation of the country. To this end, the government needs to pay more serious attention to RE options. Similarly, distributed generation and distribution, that will be localised to serve the adjoining communities holds much promise compared to the present situation of centralised generation.

7.3 Recommendation for further research

This work has established the potential of the mini hydro scheme as a better source for energy provision in Obudu. However, there are still some issues to be further studied and investigated. The recommended work includes:

- ✓ The incorporation of a dam into the mini hydro scheme to make it operational in case the flow is intermittently less than the design value as against the decision to retain the existing generator as a back-up source during such periods needs to be economically evaluated.
- ✓ Funding options for the proposed scheme needs to be investigated. This is necessary against the backdrop of the fact that the resort is government owned but private sector operated.
- ✓ The regulatory bottle necks associated with fresh investment in the energy sector in Nigeria needs to be further investigated with a view to making recommendations that will make investment in the sector less bureaucratic.

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APPENDICES

Appendix a

Executive summary of the IEA ad hoc committee report (2007) on cost of energy for different technologies.

Executive Summary

The overall objective of the study is to provide reliable information on key factors affecting the economics of electricity generation using a range of technologies. The report can serve as a resource for policy makers and industry professionals seeking to better understand generation costs of these technologies.

The calculations are based on the reference methodology adopted in previous studies, i.e., the levelised lifetime cost approach. The calculations use generic assumptions for the main technical and economic parameters as agreed upon in the *ad hoc* group of experts, e.g., economic lifetime (40 years), average load factor for base-load plants (85%) and discount rates (5% and 10%).

The costs associated with residual emissions – including greenhouse gases – are not included in the costs provided and, therefore, are not reflected in the generation costs calculated in the study.

The cost estimates do not substitute for detailed economic evaluations required by investors and utilities at the stage of project decision and implementation that should be based on project specific assumptions, using a framework adapted to the local conditions and a methodology adapted to the particular context of the investors and other stakeholders.

Moreover, the reform of electricity markets has changed the decision making in the power sector and led investors to take into account the financial risks associated with alternative options as well as their economic performance. In view of the risks they are facing in competitive markets, investors tend to favour less capital intensive and more flexible technologies. The used methodology for calculating generation costs in this study does not take business risks in competitive markets adequately into account.

The introduction of liberalisation in energy markets is removing the regulatory risk shield where integrated monopolies can transfer costs and risks from investors to consumers and taxpayers. Investors now have additional risks to consider and manage. For example, generators are no longer guaranteed the ability to recover all costs from power consumers. Nor is the future power price level known. Investors now have to internalise these risks into their investment decision making. This adds to the required rates of return and shortens the time frame that investors require to recover the capital. Private investors' required real rates of return may be higher than the 5% and 10% discount rates used in this study and the time required to recover the invested capital may be shorter than the 30 to 40 years generally used in this study.

Main results

Coal-fired generating technologies

Most coal-fired power plants have specific overnight construction costs ranging between 1000 and 1 500 USD/kWe. Construction times are around four years for most plants. The fuel prices (coal, brown coal or lignite) assumed by respondents during the economic lifetime of the plants vary widely from country to country. Expressed in the same currency using official exchange rates, the coal prices in 2010 vary by a factor of twenty. Roughly half of the responses indicate price escalation during the economic lifetime of the plant while the other half indicates price stability.

At 5% discount rate, levelised generation costs range between 25 and 50 USD/MWh for most coal-fired power plants. Generally, investment costs represent slightly more than a third of the total, while O&M costs account for some 20% and fuel for some 45%.

At 10% discount rate, the levelised generation costs of nearly all coal-fired power plants range between 35 and 60 USD/MWh. Investment costs represent around 50% in most cases. O&M cost account for some 15% or the total and fuel costs for some 35%.

Gas-fired generating technologies

For the gas-fired power plants the specific overnight construction costs in most cases range between 400 and 800 USD/kWe. In all countries, the construction costs of gas-fired plants are lower than those of coal-fired and nuclear power plants. Gas-fired power plants are built rapidly and in most cases expenditures are spread over two to three years. The O&M costs of gas-fired power plants are significantly lower than those of coal-fired or nuclear power plants. Most gas prices assumed in 2010 are ranging between 3.5 and 4.5 USD/GJ. A majority of respondents are expecting gas price escalation.

At a 5% discount rate, the levelised costs of generating electricity from gas-fired power plants vary between 37 and 60 USD/MWh but in most cases it is lower than 55 USD/MWh. The investment cost represents less than 15% of total levelised costs; while O&M cost accounts for less than 10% in most cases. Fuel cost represents on average nearly 80% of the total levelised cost and up to nearly 90% in some cases. Consequently, the assumptions made by respondents on gas prices at the date of commissioning and their escalation rates are driving factors in the estimated levelised costs of gas generated electricity.

The current gas prices are on a relatively high level. The gas price projections in 2010 of some of the respondents in the study are higher than the current level and a few are lower than the current level. The IEA gas price assumptions given in *World Energy Outlook 2004* (IEA, 2004) are markedly different.

At a 10% discount rate, levelised costs of gas-fired plants range between 40 and 63 USD/MWh. They are barely higher than at the 5% discount rate owing to their low overnight investment costs and very short construction periods. Fuel cost remains the major contributor representing 73% of total levelised generation cost, while investment and O&M shares are around 20% and 7% respectively.

Nuclear generating technologies

For the nuclear power plants the specific overnight investment costs, not including refurbishment or decommissioning, vary between 1 000 and 2000 USD/kWe for most plants. The total levelised investment costs calculated in the study include refurbishment and decommissioning costs and interest during construction. The total expense period ranges from five years in three countries to ten years in one country. In nearly all countries, 90% or more of the expenses are incurred within five years or less.

At a 5% discount rate, the levelised costs of nuclear electricity generation range between 21 and 31 USD/MWh except in two cases. Investment costs represent the largest share of total levelised costs, around 50% on average, while O&M costs represent around 30% and fuel cycle costs around 20%.

At a 10% discount rate, the levelised costs of nuclear electricity generation are in the range between 30 and 50 USD/MWh except in two cases. The share of investment in total levelised generation cost is around 70% while the other cost elements, O&M and fuel cycle, represent in average 20% and 10% respectively.

Wind generating technologies

For wind power plants the specific overnight construction costs range between 1 000 and 2 000 USD/kWe except for one offshore plant. The expense schedules reported indicate a construction period of between one to two years in most cases. The costs calculated and presented in this report for wind power plants are based on the levelised lifetime methodology used throughout the study for consistency sake. This approach does not reflect specific costs associated with wind or other intermittent renewable energy source for power generation and in particular it ignores the need for backup power to compensate for the low average availability factor as compared to base-load plants.

For intermittent renewable sources such as wind, the availability/capacity of the plant is a driving factor for levelised cost of generating electricity. The reported availability/capacity factors of wind power plants range between 17 and 38% for onshore plants, and between 40 and 45% for offshore plants except in one case.

At a 5% discount rate, levelised costs for wind power plants considered in the study range between 35 and 95 USD/MWh, but for a large number of plants the costs are below 60 USD/MWh. The share of O&M in total costs ranges between 13% and nearly 40% in one case.

At a 10% discount rate, the levelised costs of wind generated electricity range between 45 and more than 140 USD/MWh.

Micro-hydro generating technologies

The hydro power plants considered in the study are small or very small units. At a 5% discount rate, hydroelectricity generation costs range between some 40 and 80 USD/MWh for all plants except one.

At a 10% discount rate, hydroelectricity generation costs range between some 65 and 100 USD/MWh for most plants. The predominant share of investment in total levelised generation costs explains the large difference between costs at 5 and 10% discount rate.

Solar generating technologies

For solar plants the availability/capacity factors reported vary from 9% to 24%. At the higher capacity/availability factor the levelised costs of solar-generated electricity are reaching around 150 USD/MWh at a 5% discount rate and more than 200 USD/MWh at a 10% discount rate.

With the lower availability/capacity factors' the levelised costs of solar-generated electricity are approaching or well above 300 USD/MWh.

Combined heat and power generating technologies

For combined heat and power the total levelised costs of generating electricity are highly dependent on the use and value of the co-product, the heat, and are thereby very site specific. The expert group agreed on a pragmatic approach of calculating the levelised costs of generating electricity for this study.

At a 5% discount rate, the levelised costs range between 25 and 65 USD/MWh for most CHP plants.

At a 10% discount rate, the costs range between 30 and 70 USD/MWh for most plants.

Other generating technologies

Levelised costs were also computed for the remaining technologies. Considering the low number of responses for these technologies the results cannot be used outside the context of each specific case.

Conclusions

The lowest levelised costs of generating electricity from the traditional main generation technologies are within the range of 25-45 USD/MWh in most countries. The levelised costs and the ranking of technologies in each country are sensitive to the discount rate and the projected prices of natural gas and coal. The nature of risks affecting investment decisions has changed significantly with the liberalisation of electricity markets, and this has implications for determining the required rate of return on generating investments. Financial risks are perceived and assessed differently. The markets for natural gas are undergoing substantial changes on many levels. Also the coal markets are under influence from new factors.
Environmental policy is also playing a more and more important role that is likely to significantly influence fossil fuel prices in the future. Security of energy supply remains a concern for most OECD countries and may be reflected in government policies affecting generating investment in the future.

This study provides insights on the relative costs of generating technologies in the participating countries and reflects the limitations of the methodology and generic assumptions employed. The limitations inherent in this approach are stressed in the report. In particular, the cost estimates presented are not meant to represent the precise costs that would be calculated by potential investors for any specific project. This is the main reason explaining the difference between the study's findings and the current global preference in reformed electricity markets for gas-fired technologies.

Within this framework and limitations, the study suggests that none of the traditional electricity generating technologies can be expected to be the cheapest in all situations. The preferred generating technology will depend on the specific circumstances of each project. The study indeed supports that on a global scale there is room and opportunity for all efficient generating technologies.