UNIVERSITY OF NAIROBI

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EVALUATION OF THE VIABILITY OF SOLAR AND WIND POWER SYSTEM HYBRIDIZATION FOR SAFARICOM OFF-GRID GSM BASE STATION SITES

By:

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JULY 2017

DECLARATION

I, Patrick Odhiambo Owino, hereby declare that this thesis is my original work. To the best of my knowledge, the work presented here has not been presented in any other Institution of Higher Learning.

.... 1/7/17.....................

Patrick Odhiambo Owino   Date

This research thesis has been submitted for review with our approval as University supervisors.

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Prof. M. F. Odhori   Date 10/07/2017

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Dr W. Mwema   Date 19-07-2017

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DEDICATION

This thesis is dedicated to my family for their support, patience and love during the entire period of this study. This thesis is also dedicated to Prof. Oduori who has been a great source of inspiration and motivation.

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LIST OF ABBREVIATIONS

2G	Second-generation wireless telephone technology
3G	Third-generation wireless mobile telecommunications technology
4G	Fourth-generation wireless mobile telecommunications technology
AC	Alternating Current
AGM	Absorbed Glass Mat
AH	Ampere hours
ASAL	Arid and Semi-Arid Lands
AWEA	American Wind Energy Association
BSC	Base Station Controller
BTS	Base Transceiver Station
CAPEX	Capital Expenditure
CO_2	Carbon Dioxide gas
DC	Direct Current
DG	Diesel Generator
DOE	Department Of Energy
GHI	Global Horizontal Irradiance
GPRS	General packet radio service
GSM	Global System for Mobile Communication
HDGE	Human Dimensions of Global Environmental change
HOMER	Hybrid Optimization Model of Electric Renewables

HPS	Hybrid Power System
HSPDA	High Speed Downlink Packet Access
HybridGEN	integrated renewable power systems offer sustainable energy solutions to all types of load
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producers
KP	Kenya Power
kVA	Kilo Volt Amperes
kWh/yr	kilowatt hour per year
LCD	Liquid Crystal Display
LCPD	Large Combustion Plant Directive
MRI	Midwest Research Institute
MSR	Multi-Standard Radio
MWH	Megawatt hour
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
OPEX	Operating Expenditure
PCB	Printed Circuit Board
PIC	Peripheral Interface Controller
PV	Photovoltaic
ROI	Return On Investment
SOC	System On Chip
SWERA	Solar and Wind Energy Resource Assessment

TCO	Total Cost of Ownership
TRX	Electricity lines
VRLA	Valve Regulated Lead Acid
WiMAX	Worldwide Interoperability for Microwave Access

EXECUTIVE SUMMARY

To enable people in remote marginalized areas, communicate with the rest of the world, it has been increasingly important for the telecommunication network providers to install transmitting base stations in these regions. The study focused on the use of a hybrid system consisting of diesel generator, the solar panels and wind turbine generator. Diesel generators provides energy all the time, whereas PV and wind are dependent on of solar radiation and wind speed, respectively.

Load demand and renewable resources (wind speeds and solar radiation) are the major problems that face power generation using hybrid systems. The major concern therefore is the accurate choice of system components that economically satisfy the load demand.

The study looked at Safaricom Limited. Safaricom Limited formed in May 2000 as a joint venture between Telkom Kenya and Vodafone UK. It enjoys countrywide network coverage of over 80% of the Kenyan population estimated at 46 million people in the 2016 UNESCO population estimate; it provides voice and data services that include GPRS, EDGE, HSPDA and WiMAX.

Safaricom has about 2,500 base stations with a mix of 2G, 3G, 4G and WiMAX technologies, most of which are powered the grid with diesel generator as back up. However, 10% of the sites are solely on diesel-powered generators on a 24-hour basis. Additionally, 3% of the BTS are on renewable energy hybrid system.

This research sought to evaluate the viability of solar, wind and diesel generator energy sources that are used to power typical remote off grid GSM base stations. The objectives of the study were to establish the Return on Investment (ROI) and Total Cost of Ownership (TCO) for the various hybrid configurations, find out the main hindrance to the deployment of alternative energy solutions by operators, assess the environmental impact in deploying the different alternative sources of energy, establish the regulations and standards in place for benchmarking various alternative energy technologies and establish the key players in the provision of renewable energy technologies in the telecommunications sector in Kenya.

Hybrid systems seek to reduce operation, maintenance and logistics cost by minimizing diesel runtime and consumption of fuel. To achieve this, the generator only runs when the batteries reach a preset discharge level to recharge the battery and supply excess load.

The study employed both quantitative and qualitative methods for data acquisition. The evaluation of the viability of solar and wind hybridization of Safaricom off-grid GSM base station site was carried out in Sekanani, Masai Mara, Narok County in Kenya.

HOMER was used to optimize the various energy options in the study. For optimal hybrid system and determination of the proper electrical power supply that meets the required load demand at the lowest possible cost several simulations were done.
The diesel engine at the site would consume between 2.02 litres per hour and 5.5 litres per hour. The Perkins Engine 400 series at the site has the capacity to consume up to 10.4 litres per hour, on maximum load. It is apparent that the engine is not put to maximum capacity, possibly due to the existence of the other sources of renewable energy.

Total annual energy demand is therefore the energy to run the BTS and its auxiliaries and the energy to have the batteries fully charged. The main power requirement annually is 17.5 MWh. The total energy produced annually from the photovoltaic panels is 20.83 MWh, this is the value given by HOMER for the region of study.

The total energy produced from the diesel generator set for the year was 5.38MWh. The month of December contributed the highest from the diesel generator set at 519KWh. However, in this month the speed of wind recorded was high and it was expected that there would be low use of diesel generator.

The total hybrid energy produced at Sekanani therefore was the energy from wind, solar and diesel engine. This translates to (Solar panels 20.83 MWh + Wind turbine 11.55 MWh + Diesel Engine 5.38 MWh) = Total 37.76 MWh against the net requirement of the BTS and the storage batteries annual demand of 17.50MWh. The amount of energy generated from green sources in the hybrid per annum is 32.38 MWh which is adequate to satisfy the BTS and its accessories demand which is 17.50 MWh. The diesel generator is just supplementing the energy demand by only 5.38 MWh annually. Amount of excess energy 37.75-17.50MWh = 20.26MWh annually. An indication of overcapacity.

It is worth noting that even though the initial installation cost of the hybrid system is higher than the installation of a diesel engine, in the long run the cost of operating a hybrid system is lower than the cost of running a diesel system. The operating cost of a hybrid system of PV, wind and diesel is three times lower than a diesel engine system.
On economic terms the Net Present Costs (NPC) of various combinations from HOMER simulations were found to be as follows:

- Genset and ancillaries NPC/kWh is $21.8/MWh
- Solar PV and Wind Turbine Hybrid and ancillaries NPC/kWh is $8.24/MWh
- Solar PV and Wind Turbine and Genset Hybrid and ancillaries NPC/kWh is $6.89/MWh

Therefore, the hybrid architect with the least net present cost is the triplet one that combines all the three sources of energy.

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CHAPTER 1

1.0 INTRODUCTION

To enable people in remote marginalized areas, communicate with the rest of the world, it has been increasingly important for the telecommunication network providers to install transmitting base stations in these regions. In remote areas the grid extension is expensive and fuel cost also increase with remoteness of the area. Realistic alternatives include renewable energy sources such as small hydroelectric generation, solar and wind (Nandi and Ghosh, 2009; Dihrab and Sopian, 2010).

Environmental concerns and costs attributed to conventional electrical sources of energy have resulted in surged interest in alternative energy sources. Major generation of power takes place in centralized stations and they use coal, oil, gas, water or fissile nuclear material as the main fuel source. Additionally, geothermal power generation is also taking center stage. There are problems facing development of methods of generating power based on conventional fuels. Generation of hydro-power is restricted to geographically appropriate areas in that it is influenced by the area's' topography and its rainfall patterns.

Coal reserves on the other hand are limited and not renewable. The possible dangers of nuclear power have been widely publicized, particularly those concerning the storage and military use of nuclear waste material. Nevertheless, to assist in maintaining electrical supply in many societies, it seems likely that an increasing nuclear power presence, using breeder and possibly fusion reactors, will be accepted. To achieve this and to also aid in management of existing fossil-fuel resources, it is essential that future energy research and development be increasingly concerned with the so called nonconventional methods of generation.

Wind and solar energy sources are viable options for future power generation. They can be accessed in remote areas where grid power supply is inaccessible. Wind and solar hybrid models with appropriate storage systems have received keen interest in the last few years (Bekele, 2009). There are different configurations of renewable and conventional energy sources that have been deployed for telecommunication purposes. Examples include Diesel-Battery; Solar-Diesel-Battery; Wind-Diesel-Battery; Solar-Wind-Diesel-Battery; Solar-Hydro-Diesel-Battery, among others. The choice of renewable power options is partly determined by the region in which the facility is located. For instance, the performance of solar and wind energy systems (singly or in combination) is strongly dependent on the climatic conditions at the location, while the hydroelectric resource depends on the location's topography and rainfall patterns, (Bekele, G., Palm, B, 2010),

The GSM Association representing the interests of the worldwide mobile communications industry estimates that "nearly 639,000 off-grid base station pieces of equipment providing cellular network coverage were rolled out by 2012 across South and South East Asia, The Middle East and Africa where grid availability is among the lowest in the world" (Ashok, 2007). Energy accounts for up to 60% of the network operating expenses and corporate policies are now in place to reduce the carbon footprint, Ashok, (2007).

The objective of this work was to evaluate the viability of using renewable energy systems (PV/Battery, Wind/Battery, hybrid PV/Wind/Battery) for electrification of a typical isolated BTS in Narok County. In view of the fact that these areas have high irradiation levels, and with Masai Mara situated in an area with high wind speeds, the necessary energy requirements may be met by renewable energy conversion systems such as wind turbines and PV panels alone. This site in Narok was ideal for this study because it met all the inclusion criteria the study was looking for. It was off grid and had employed the use of renewable energy; solar energy and wind energy and a backup diesel generator. In light of the low uptake of hybridization especially the combination of solar, diesel generator and wind power in telecommunication in Kenya it was necessary to evaluate an already installed system and determine the factors that would scale up the uptake

1.1 HYBRID POWER SYSTEMS

A hybrid powered system (HPS) can be described as an electricity production system whose supply consists of a combination of two or more types of electricity generating sources like solar photovoltaic panels, wind turbine generators, hydro plants, and/or fuel generators. The useful components of hybrid systems considered in this study are the diesel generator, the solar photovoltaic panels and wind turbine generator. A diesel generator can provide energy at any time, whereas energy from PV and wind is greatly dependent on the availability of solar radiation and wind speed, respectively (Wichert, 1997; Yu, Pan, & Xiang, 2005). This makes the hybrid generator system more reliable, and it can be used to provide electrical power when PV and/or wind fail to satisfy the load.

1.2 HYBRID POWER SYSTEM CONFIGURATION

The major problem faced in power generation using the hybrid system is the variation in load demand and renewable resources (solar radiation and wind speeds). Therefore, the major concern in the design of an electric power system that utilizes renewable energy sources is the accurate selection of the combination of system components that can economically satisfy the load demand, (Peterson, 1999).

Based on the cost of components, fuel, labour, transportation and maintenance, it is desired to evaluate the most cost-effective size of all components to meet the predicted peak loads. In this optimization problem, hybrid system sizing is done with the aim of minimizing net present costs while meeting a given demand reliably and cost-effectively. One method of doing this is to incorporate computer simulation models for hybrid power systems (Elsholz, 1999).

1.3 SAFARICOM - BACKGROUND

Safaricom Limited was formed in May 2000 as a joint venture between Telkom Kenya and Vodafone UK. Safaricom is the leading mobile service provider in Kenya, with a subscriber base of over18 million, a market share of 80% and MPESA subscribers at 14 million clients. The present shareholding of Safaricom is 40% Vodafone, 35% GOK and 25% Public through the Nairobi Stock Exchange (NSE). It enjoys countrywide network coverage of over 80% of the Kenyan population estimated at 46 million people in the 2016 UNESCO population estimate; it provides voice and data services that include GPRS, EDGE, HSDPA and WiMAX. It also operates a Mobile Money Service (MPESA) and other value added services such as paying bills and buying goods and services. The countrywide network has rolled out 3G in 50% of the sites in the network.

Safaricom has about 2,500 base stations with a mix of 2G, 3G, 4G and WiMAX technologies. Most of the sites are powered by grid power with backup diesel generators. However, 10% of the sites are solely on diesel powered generators on a 24 hour basis. Additionally, 3% of the BTS are on renewable energy hybrid system. Safaricom is focused on reduction of generator running hours to save on OPEX, conserve the environment (reduce her carbon footprint), present a green image and lead in green business.

1.3.2 SAFARICOM ENERGY CHALLENGES

Safaricom faces a myriad of challenges with regard to electrical energy. Safaricom sites consume an average of 700,000 liters of diesel per month, 70% of which is consumed at off-grid sites at a cost of Ksh 87 million. The company runs a total of 2,308 sites with diesel engine generators (DEG). The company faces fuel delivery logistics problems to the remote areas due to poor road network. They further experience theft and adulteration.

1.3.3 SAFARICOM SOLUTION TO CHALLENGES

In an effort to mitigate some of the challenges, Safaricom has opted to invest in Solar and Wind energy for connection to BTS sites that are off the grid. They have further invested in remote CCTV to curb theft and control entry onto the sites.

1.4 STATEMENT OF THE PROBLEM

Even though Renewable energy contributes significantly to the reduction of energy cost, if properly integrated into the BTS energy sources, Safaricom continues to use diesel generator sets for off-grid base stations. Diesel generator sets have not been instrumental in mitigating present day energy problems such as price instability for fossil based fuels; global warming and climate change not to mention further increase in operation cost due to refueling and periodic maintenance at remote sites. They contribute significantly to environmental pollution. Recognizing this problem, the researcher evaluated the viability of solar and wind hybridization for Safaricom off-grid GSM base station sites as a range of professionally designed renewable energy power solutions incorporating an innovative constant speed diesel generator, HybridGEN, solar (PV) modules and small wind turbines.

1.5 PURPOSE OF THE STUDY

The purpose of this research was to evaluate the viability of solar, wind and diesel generator energy sources that are used to power typical remote off grid GSM base stations.

1.6 RESEARCH OBJECTIVES

The study endeavoured to address the following objectives;

i. To establish the ROI and TCO for the various possible hybrid configurations.

ii. To find out the main hindrance to the deployment of alternative energy solutions by operators.

iii. To assess the environmental impact in deploying the different alternative sources of energy.

iv. To establish the regulations and standards in place for benchmarking various alternative energy technologies.

v. To establish the key players in the provision of solar and wind energy technologies in the telecommunications sector in Kenya.

vi. To recommend a model prototype system based on the findings of the study.

1.7 RESEARCH QUESTIONS

The following research questions were answered in the course of this research work.

i. What is the energy OPEX as a percentage of the total OPEX at a remote off-grid GSM radio base station site?

ii. What is the TCO for a diesel generator-only operated site in comparison to a site powered with an optimized configuration of solar-wind-diesel generator combination?

iii. What are the available technology options for Solar-Wind-Generator configurations?

iv. What are the obstacles preventing the wider deployment of solar and wind as sources of power for remote off-grid GSM radio base stations?

v. What measures can be undertaken to improve the uptake of solar and wind sources of power by operators to power their remote off-grid GSM radio base stations?

1.8 JUSTIFICATION

To sustain subscriber growth, a large number of new off-grid GSM radio base stations are being built. However, rural areas pose a challenge as energy related OPEX per site is higher and revenue per site is usually lower compared to urban areas. OPEX related to wireless energy costs make up to 40-55% of direct site OPEX. Diesel generators are the most widely used sources of power for off-grid GSM base station sites. In most instances two generators are deployed at a single site in order to provide the option of rest time for each of the generators and also ensure continuity of power supply in case any one of the generators is broken down or undergoing maintenance.

The cost of operating a site on a diesel generator is usually very high due to the following; fuel cost, fuel logistics cost, fuel losses or theft, generator services, generator overhauls and generator replacements. Additionally, there is the cost of retaining an attendant to regularly check the levels of fuel. Solar and wind options are generally favoured and provide greater financial and environmental benefits when the network facility is far away from the grid and/or when the delivery of fuel is difficult. The consequence of solar and wind options is that they must be carefully engineered and configured in order to meet the operating conditions and load requirements of the GSM base station.

In order for a GSM operator to make a decision as to which power source to deploy at a remote off-grid radio site it is important that a proper study is carried out and results used to provide guidance on the best option.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is devoted to a review of research done by other scholars on the viability of solar and wind hybridization on off-grid telecommunication base transmitting stations in other parts of the world.

2.2 CRITICAL REVIEW OF LITERATURE

2.2.1 HYBRID POWER SYSTEM

A case study of different stand-alone hybrid blends was done in remote area Barwani in India and it was revealed that PV-Wind-Battery-DG hybrid is the most ideal solution regarding cost and emissions among all various hybrid system combinations (S.C. Gupta, 2016).

A photovoltaic-diesel engine hybrid systems are beneficial as they improve reliability and energy services, they reduce pollution and emissions, additionally they provide continuous power supply, increasing operational life, and reducing cost, and more efficient use of power. The photovoltaic hybrid systems work on the principle that solar will be the first choice of supplying load and excess energy produced will be stored in battery with the diesel generator set as a secondary source of energy. A microprocessor based controller to manage the energy supplied and load demand controls the system. The hybrid system consists of diesel generators with electronic control system, lead acid battery system, solar PV, inverter module and system controller with remote monitoring capability. (Sopian & Othman , 2005).

Hybrid power systems make use of both the solar PV and wind turbine to produce electricity that can be supplemented by diesel generators. It is configured in a way that considers the power produced from the three sources. It is analyzed for various photovoltaic array sizes and wind turbines with respect to a diesel generator to operate in tandem with the battery system. The conversion of the DC power from the PV arrays is determined by the controller unit in relation to the diesel generation operation following the load profiles. The batteries will be charged with energy from wind and solar modules as well as from the diesel generator this is controlled by the charge controller. The main objective of hybrid system is to reduce the cost of operation and maintenance and cost of logistic by minimizing diesel runtime and fuel consumption. To achieve this, the generator only runs when it is needed to recharge the battery and to supply excess load. It is only started when the battery reaches a preset discharge level and is run at full capacity until the battery is fully recharged and then shut down.

Wind speeds are usually low when the sun shines brightest and longest. Because the peak operating times for wind and solar systems occur at different times of the day and year, hybrid systems are more likely to produce power when it is needed.

Many hybrid systems are stand-alone systems, which operate “off-grid” – not connected to an electricity distribution system. For the times when neither the wind nor the solar system are producing, most hybrid systems provide power through batteries and/or an engine generator powered by conventional fuels, such as diesel. If the batteries run low, the engine generator can power and recharge the batteries.

Adding an engine generator makes the system more complex, but modern electronic controllers can operate these systems automatically. An engine generator can also reduce the size of the other components needed for the system, keeping in mind that the storage capacity must be large enough to supply electrical needs during non-charging periods. Battery banks are typically sized to supply the electric load for one to three days.

The renewable energy system is an option which would have been the best for network operators, but it cannot continuously provide energy due to the low availability in different seasons. Hybridizing diesel with renewable energy sources (solar and/or wind power) will be one method of reducing call-cost and improving the services of wireless telephony from the angle of powering the base station sites. This will allow telecommunication companies to circumvent rising energy costs and realize an excellent Return on Investment (ROI) and make communications more accessible while minimizing their detrimental environmental impact.

Recent years have seen a surge in research on the power consumption aspect of wireless and cellular networks due to the increasing concern on rising global energy demand and decreasing the industry's overall carbon footprint. The power consumption of cellular networks also constitutes a large portion of the operating expenses for service providers (W. Vereecken, 2011). Within a cellular network, the power needed to run a base transceiver station (BTS) as well as the corresponding cooling facilities forms the major share of energy consumption. This strengthens the motivation for the development of BTS energy savings techniques and/or finding new solutions for the uninterruptable and alternative BTS power supplies.

Previous methods for reducing the power consumption of a BTS can be largely classified into four categories (Roy, 2008). One approach is to relocate the radio frequency (RF) converters and power amplifiers from the base of the station to the top of the tower close to the antenna and connecting them via fiber cable. The second method is based on exploiting the economy mode (ECO) feature, e.g. turning the transceivers on/off during low traffic conditions to improve BTS energy efficiency (Ericsson, 2007). The third possibility is to use advanced climate control for air conditioners to conserve power and/or using passively-cooled cabinets (Tu, 2011).

The last scheme is based on using higher efficiency rectifiers as part of BTS installations (Roy, 2008). Renewable energy sources such as wind and solar power represent attractive and economic solutions for alternative BTS energy sources. These resources jointly with other electricity generators, such as diesel generators and national electric grid, can create a hybrid power system (HPS) to provide a more reliable power supply for BTSs, while reducing their operational cost. As examples of such systems, a hybrid solar wind-batteries-diesel/electric grid system that can substantially reduce the operational cost has been proposed. A time-step algorithm has also been proposed to properly dimension the hybrid system, in order to partially- or fully-meet the load demands of a BTS, while evaluating the amount of carbon dioxide (CO_2) emissions. Moreover, the HPSs require control and communication systems to locally and resourcefully manage supply and demand within a BTS. (P. D. Diamantoulakis et al, 2013).

Diamantoulakis et al in their paper, first developed a sensor control system and communication network to facilitate power measurements from BTS loads and local generators and provide communication among sensor nodes (P. D. Diamantoulakis et al, 2013). Previously proposed

HPS can work in two disconnected and connected modes of operations by measuring the deficit or surplus in electrical power supply. In the former mode, it locally balances supply and demand and if there is a surplus in energy, there is no possibility to transfer/sell this energy to the grid. In the latter mode, the HPS employs the power grid besides local energy resources to balance supply and demand. In this case, there is no capability for energy consumption scheduling (ECS) to facilitate real-time energy management, and consequently reduce further cost of operation.

Cost minimization can be achieved by finding a suitable control strategy in an appropriate system configuration of the hybrid. Variables being, PV module number, PV module slope angle, wind turbine number and installation height, battery number, diesel generator type and its starting and stopping points. The diesel generator is just used as a backup in the process to meet the extra load demands which the (solar and wind energy) could not produce. The hybrid increases the systems reliability with decreased fuel consumption output and decreased battery size.

Weather is a very important aspect in this hybrid system. In this particular case, a sizing method was developed to attain the global optimum and it was used to evaluate hybrid solar-wind and hybrid solar-wind-diesel system for off-grid applications and to obtain the desired system performance with minimum Annualized Cost of System. (Wei, 2007).

2.2.2 MAIN HINDRANCE TO THE DEPLOYMENT OF ALTERNATIVE ENERGY SOLUTIONS

Alternative energy solutions have been in Kenya for some time. However, the low pace of growth in the country is noticeable compared to the other developing countries (SREP, 2011).

Currently in Kenya, most renewable energy systems technologies are available although market penetration is notably low and the existence of these technologies is rarely known by potential users.

Previous studies by SWERA on policy analysis and market penetration for wind energy and applicable to solar identified a number of existing barriers and constraints. Among these were:

- The traditional duplicity of the distortion of the energy prices due to hidden subsidies especially in the power sector;
- For a long time, there has been no suitable legal and regulatory framework and there has been lack of institutional support to promote wide spread use of wind energy; now with the enactment of the Energy Act and setting up of the Energy Regulatory Commission there is hope that some of the problems will be addressed
- High initial capital cost of the systems despite gradual reduction of the indirect taxes by the Government over the years with no significant price reductions;
- Lack of awareness of potential opportunities, market niche for electricity production and the economic benefits offered by wind energy technology and,
- Lack of appropriate credit and financing mechanisms to facilitate acquisition of wind power technology by the rural population
- Associated capital flight in acquiring renewable energy sources especially solar and wind energy, where up to 90% of the costs go to suppliers abroad.

2.2.3 THE ENVIRONMENTAL IMPACT IN DEPLOYING THE DIFFERENT ALTERNATIVE SOURCES OF ENERGY

This section of the report attempts to address some of the environmental impact associated with the deployment of alternative sources of energy. All energy sources have some impact on the environment. Fossil fuels do more harm than renewable energy sources by most measures, including air and water pollution, damage to public health, wildlife and habitat loss, water use, land use, and global warming emissions.

The exact type and intensity of the environmental impact varies depending on the specific technology used, the geographic location and a number of other factors. By understanding the current and potential environmental issues associated with each non-renewable energy source, steps can be taken to effectively avoid or minimize the impacts the non-renewable sources continue to make on our electricity supply.

The sun provides a tremendous resource for generating clean and sustainable electricity without toxic pollution or global warming emissions. The impact on land use and habitat loss may be minimal on small scale solar production. However, when there is large scale solar production, issues of land use and habitat loss may arise. At the manufacturing level there could be issues of hazardous materials and use of water.

- Land use issues can only occur when the systems are large and require vast area. However, for roof tops, the solar panel required does not pose such a risk. Estimates for utility-scale PV systems range from 1.4 to 4 hectares per megawatt.

- Although Solar PV cells do not use water for generating electricity, as in all manufacturing processes, some water is used to manufacture solar PV components. The PV cell manufacturing process includes a number of hazardous materials, most of which are used to clean and purify the semiconductor surface. These chemicals, similar to those used in the general semiconductor industry, include hydrochloric acid, sulfuric acid, nitric acid, hydrogen fluoride, 1,1,1-trichloroethane, and acetone. Workers also face risks associated with inhaling silicon dust. Thus, PV manufacturers must ensure that workers are not harmed by exposure to these chemicals and that manufacturing waste products are disposed of properly.

- Thin-film PV cells contain a number of more toxic materials than those used in traditional silicon photovoltaic cells, including gallium arsenide, copper-indium-gallium-diselenide, and cadmium-telluride. If not handled and disposed of properly, these materials could pose serious environmental or public health threat. However, manufacturers have a strong financial incentive to ensure that these highly valuable and often rare materials are recycled rather than thrown away.

- While there are no global warming emissions associated with generating electricity from solar energy, there are emissions associated with other stages of the solar life-cycle, including manufacturing, materials transportation, installation, maintenance, and decommissioning and dismantlement. Most estimates of life-cycle emissions for photovoltaic systems are between 0.07 and 0.18 pounds of carbon dioxide equivalent per kilowatt-hour (IPCC, 2011).

CHAPTER 3

3.0 MATERIALS AND METHODS

This chapter describes the methods and tools that were used in this study. It describes the key sources of information, the tools used, the area of study, the energy options evaluated, data collection, questionnaire development and data analysis.

3.1 DESIGN

The study employed both quantitative and qualitative methods for data acquisition. Based on the background discussed thus far, the evaluation of the viability of solar and wind hybridization of Safaricom off-grid GSM base station sites was carried out in Sekanani, Masai Mara, Narok County in Kenya.

The Hybrid Optimization Model for Electric Renewables (HOMER) software, a public domain software package, was used to optimize the various energy options in the study. As mentioned earlier, the main objective of this research was to evaluate the viability of a hybrid solar-wind-diesel engine system as a source of power for typical remote off-grid GSM base stations.

3.2 HOMER

Hybrid Optimization Model for Electric Renewables (HOMER) is a software package copyrighted by the Midwest Research Institute (MRI) and provided by the National Renewable Energy Laboratory (NREL) operated by MRI for the U.S. Department of Energy (DOE). For this study a students' copy of the software was downloaded and a license obtained for use of the software. Websites providing data sources on solar radiation and wind speed and information on sources of power components such as wind turbines, generators and batteries were also accessed. HOMER helps find the least cost combination of components that meet a required load based on an hourly analysis of the input variables such as wind and solar data. For systems that meet the yearly load, the life-cycle cost is also estimated by the software.

In this study the power sources that were evaluated included photovoltaic (PV); wind turbine and diesel generators. Hourly load demands (Base Station Site perspective) were entered in HOMER to generate daily and monthly load profiles for a year. This was then tabulated.

The study area was located in an isolated section of the Masai Mara game reserve next to the Bush Tops lodge in Kenya. The exact coordinates of the site are: Latitude; 02^0 17’ 51.45” S and Longitude; 035^0 02’ 34.81” E. This location is endowed with significant solar and wind resources. This area has an estimated average wind speed of between 3-10 m/s and a high solar energy potential since it receives daily insolation of between 4-6kWh/m^2.This location being rich in solar radiation the first set-up scenario investigated was the cost effectiveness of using only PV together with a diesel generator. How the cost would change if a wind turbine was added to the PV-generator system was then investigated. Once this was established the components to be included in the system design, the quantities, and the sizes, were identified. Subsequently, the technology options, component costs, and available resources were entered into the software. HOMER then provided different feasible system configurations, and these were compared to the net cost of the equipment at the time of making the installation.

3.3 SECONDARY DATA REVIEW

The study involved a review of available literature on off-grid power supply. It further looked at secondary data on daily global horizontal solar radiation and data on daily wind energy.

Data for the daily load demand of the communication equipment and its accessories were obtained from HOMER for the selected site.

The study reviewed both technical data and the relevant financial records.

- Daily load records
- Fuel records
- Maintenance records
- Model of batteries
- Energy capacity

3.4 DATA ANALYSIS AND PRESENTATION

Data on solar radiation, wind speed, and systems components specification were supplied to HOMER Software. Performances of several simulations were done to obtain the optimal hybrid system and determination of the proper electrical power supply that meets the system demand at the lowest possible cost the required load demand. Data from the various sources were input in Excel software and tabulated. The tabulated data is presented in graphs of various shapes suitable with the data collected.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter reports the findings from the site visit and discussions with the Safaricom field personnel and staff of Safaricom. The study was carried out in Masai Mara, the Safaricom site that had employed a hybrid system of photovoltaic, wind turbine and diesel generator. These met the study specifications. The chapter is organized to address the objectives of the study. The first section gives an overview of the equipment involved and the layout of the plant, giving insight into the flow of energy in the plant. The chapter subsequently addresses the objectives of the study i.e. the effect on Return on Investment (ROI) and TCO for the various hybrid configurations, the main hindrance to the deployment of alternative energy solutions by operators, the environmental impact in deploying the different alternative sources of energy, the regulations and standards in place to benchmark the various alternative energy technologies and finally the key players in the provision of solar and wind energy technologies in the telecommunication sector in Kenya.

4.2 THE FINDINGS FROM THE BTS IN SEKANANI

4.2.1 THE HYBRID POWERED BTS AT SEKANANI IN MASAI MARA

The following paragraphs describe the energy sources and flow at the BTS, as well as the load served by the power produced. The site is located at Mara Siana conservancy, directly bordering the Masai Mara game reserve, on the premises of Mara BushTops game lodge. This site is accessible by road from Sekanani gate of the Masai Mara game reserve or by air from the nearby airstrips at Siana springs and Keekorok. The exact coordinates of the site are: Latitude; 02° 17’

51.45” S and Longitude; 035° 02’ 34.81” E. Given that this study was an evaluation of the work already done by Safaricom on hybridization of the BTS it was essential to visit a site that had installed and employed a hybrid system. This would give more insight into hybridization and the researcher would gain more knowledge on reasons for that low uptake of hybridization.

4.2.2 PHOTOVOLTAIC PANELS

There are two arrays of four 250 W photovoltaic panels manufactured by Sanyo. It was observed that the photo-voltaic panels were mounted on the ground. It was further noted that there was a photovoltaic controller/regulator that links the photovoltaic cells to the battery bank. This controller is built for outdoor application and is used to regulate solar energy flow to the storage battery bank. Figure 1 illustrates the mounting of the solar panels. It further shows the shadowing problem from the two tall masts (wind turbine and communication). The shadow from the two masts can also be noted in the same figure which makes a strong case for a prototype where the solar panels mounted on top of the power house to avoid shadowing and collect more solar energy. Raising the device above the ground could definitely improve the hybrid system and reduce the usage of the diesel generator.

Figure 1: Solar Panel mounted on the ground

4.2.3 THE WIND GENERATOR

The wind generator on the site is a Bergey Excel 10 model rated at a maximum power output of 8.9kW. The Bergey EXCEL 10 is an upwind horizontal-axis wind turbine designed for distributed generation application and, where possible it can be connected to the power grid. It has a rotor system that consists of three fiberglass blades. The blades convert the energy of the wind into rotational forces that drive the alternator. Figure 2 illustrates the two masts mounted on the site whose shadow spill over to the solar panels, it further shows how close they are to each other.

Figure 2: Wind Turbine and Communication Mast

Wind speeds vary heavily and therefore there is need to have stronger blades that can be able to withstand the changes. As shown in Figure 2, the generator is mounted on a mast of lattice type at a height of 24 m. The rotor of the EXCEL 10 begins to rotate when the wind speed reaches approximately 3.6 m/s. Once started, the rotor may continue to turn in winds below 2.2 m/s, but the system will not be producing power below this wind speed. During periods of high wind speeds, the AutoFurl system will automatically protect the wind turbine. The generator is designed for a maximum wind speed of 54 m/s, and therefore at any wind speed above this the generator will definitely need protection and AutoFurl suits the best candidate for this. Furling means that the rotor is turned away from the wind. When furled, the power output of the turbine will be reduced. In winds between 15 m/s and 20 m/s it is normal for the turbine to repeatedly furl and unfurl.

Figure 3 is the Powersync II inverter that converts the “variable AC” from the Bergey EXCEL 10 turbine into utility grade electricity so that it can be connected to the wiring in the BTS. This conversion is electronic and is designed to operate automatically. The Powersync II has a digital display that provides information on the status of the system, its current output power, and its cumulative energy production. The Powersync II inverter is connected to the BTS circuit through a dedicated 70 A breaker. Before opening the Powersync II enclosure, the breaker must be turned off and the tower disconnect switch (indicated in red) must be switched OFF, to avoid electrical shock.

Figure 3: Wind Turbine Power Unit

4.2.4 SEALED VALVE REGULATED LEAD ACID BATTERY BANKS (VLRA)

The batteries are sealed Valve Regulated Lead Acid Battery Banks (VRLA). The VRLA batteries are batteries whose electrolytes are captive preventing any spillover even when punctured. These have electrolyte mixed with silica dust to form an immobilized gel. These types of batteries do not require maintenance or additional electrolyte or water.

The batteries have a charge regulator that controls the rate at which the batteries are charged or discharged. This prevents overcharging the batteries and may also help keep the batteries safe incase an overvoltage condition occurs which can reduce battery life.

These batteries are described as high capacity sealed VRLA gelled batteries 48V DC. The batteries are designed to withstand high temperatures. The battery bank is rated at 2000 Ah of two banks each of 1000 Ah. The number of cycles for the battery banks is at least 1000 at a depth of discharge of 80%.

There is an inverter used to convert the available DC power supplied by the rectifier and battery systems to a nominal 240 volt AC power for loads.

4.2.5 SYSTEM OPERATION

The system is configured to have energy stored in the battery banks as a default from both green sources (solar, wind) and diesel generator. The system then supplies 48V DC energy from the extended battery banks directly or 240V, 50Hz AC energy via inverters.

4.2.6 BATTERY OPERATION

The extended gelled VRLA batteries are charged by either wind or solar energy via charge regulators. If these two sources are not sufficient, only then will the diesel generator be powered to charge the battery banks, 48V DC power produced by the battery is then used directly to power the telecommunications equipment. Loads requiring AC power, such as the cooling of the BTS room, are to be powered from the battery bank via an inverter system. This battery operation continues until the battery bank is drained to a predetermined value. At this value, the generator is run to supply the load and charge drained batteries.

The system is configured in such a way that the green sources charge the battery as it is supplying the load. This way, a low battery voltage condition is avoided unless the rate of discharge is much higher than the rate of charge from 'green' sources. Figure 4 illustrates the battery bank as configured on site. There are 24 batteries of 2 V each connected in series with an ability to store and deliver 48V DC.

Figure 4: Battery Unit (Storage Power) 24 batteries as configured in the site

4.2.7 LOW VOLTAGE DISCONNECT SWITCH

A Low voltage disconnect switching system is provided and operates in two stages;

(a) Stage 1; Disconnection of non-priority loads at a pre-determined voltage, V1 (variable).

(b) Stage 2: Disconnection of priority loads at a pre-determined voltage V2 (variable). This voltage is lower than the disconnect voltage for stage 1, V1. At this voltage, V2 all loads are disconnected from the battery bank to avoid further battery discharge to save it from irreparable deep discharge.

4.2.8 DIESEL GENERATOR OPERATION

The diesel generator operates only during charge drought from green sources. It boosts battery charge via an appropriately sized rectifier. During its operation, AC power loads are supplied directly, while DC loads are supplied via the rectifier. As soon as the battery is fully charged, the system reverts to battery operation with both green sources being default choices for battery charging.

The diesel generator running sequence is controlled in such a way that once it comes into operation, it must run until such a time that the battery bank is fully charged as compared to short and erratic intervals. The generator is started by a low battery voltage but stopped using a timer to ensure that the battery bank is fully charged.

This way, the battery bank is fully charged thus managing the cyclic life of the battery banks. The average generator running hours do not exceed four hours in each 24-hour period.

4.2.9 GENERATOR BY-PASS OPERATION

A generator by-pass switch installed in the system redirects power from the generator directly to the load, being an AC. The power for charging the batteries and the DC from the batteries to the load will pass through the inverter. This operation can be initiated automatically or manually.

4.2.10 HIGH LOAD DEMAND

The inverter system is configured to switch on the generator should the load surpass inverter capacity for a specific time, for instance three minutes. This restriction on operation is to protect the inverter from damage due to overload. If the load demand is much lower than inverter capacity, then the inverter supplies the load and charges the battery bank.

4.2.11 DIESEL ENGINE EXERCISER

In an invent that the engine has been idle for a long period of time, the system has been configured to exercise the diesel engine. The engine exercise would run for 15 minutes at no load.

4.2.12 SYSTEM SIZING

The total system load is designed to provide a total of 4 kW of DC power at 48 V and 3.52 kW equivalent of air conditioning load.

4.2.13 RECTIFIER

The purpose of the rectifier is to charge the 2000 Ah battery bank whenever solar and wind sources are in short supply. For the rectifier system to effectively charge the battery bank taking into account value of 10μF capacitor used to smoothen the voltage, the effective rectifier current required will be 400 A. This requires a 20 kW rectifier for effective operation.

4.2.14 INVERTER

The inverter is sized to supply AC load equivalent to 3 kW at peak demand. The purpose of the inverter is to supply AC power to AC air-conditioning in the BTS room.

4.2.15 HOUSING AND COOLING

The battery bank is housed in a well-ventilated compartment consisting of free cooling and active cooling. The free cooling system operates to keep the temperature low to a preset value. Active cooling comes into operation only when a high temperature is experienced. Generally, 25℃ is the preferred high temperature cut-off for battery banks.

4.2.16 POWER OUTPUT

The system power output is provided from two separate boards. These boards are housed within the rectifier/battery housing and labeled as,

(a) AC Power Output – with three single-phase circuit breakers of 20 A.

(b) DC Power output- with 4 x 50 A DC breakers for non-priority load and 10 A x 3 breakers for priority loads.

4.2.17 ALARM PROVISION

The system is designed to have alarm provision escalation to a remote monitoring center via the GSM network. Critical alarms provided for are:

- Inverter alarms
- Rectifier alarms
- Battery bank alarms
- Generator alarms
- Wind generator alarms
- Photovoltaic array alarms
- Temperature alarms

4.2.18 THE EQUIPMENT HOUSING

The equipment is housed in a perimeter wall closely guarded by staff and a remote sensor that sends signals to the controller any time someone gains access to the site. There is a mast for the communication equipment, a mast for the wind mill and the solar panels mounted on the ground.

4.3 SIMULATION AND OPTIMIZATION FINDINGS

4.3.1 MONTHLY AVERAGE SOLAR GLOBAL HORIZONTAL IRRADIANCE (GHI)AND WIND SPEED DATA

The following dataset was downloaded from the NREL database using HOMER and used to project the amount of energy available for the photovoltaic solar panels at the Sekanani site in the Masai Mara. Figure 5 illustrates the monthly average Solar Global Horizontal Irradiance data as reported by NREL, average wind speed in cm/s and average wind energy in kWh. The units are modified for the sake of graph visibility. It is evident from the graph that there are higher peak radiations in February and September and peak wind speeds/energy in August. Equinoxes are also experienced around March and September, a fact that supports the periods of peaks radiations and wind speeds. These are the periods during which there are higher wind energy. There is sharp a drop of wind speeds in December to January there is a sharp rise in solar radiation during that time. This helps in the sustenance of power supply of the hybrid, at low wind speeds solar subsidizes. Peaks of wind and solar energy supplies are experienced between August and September.

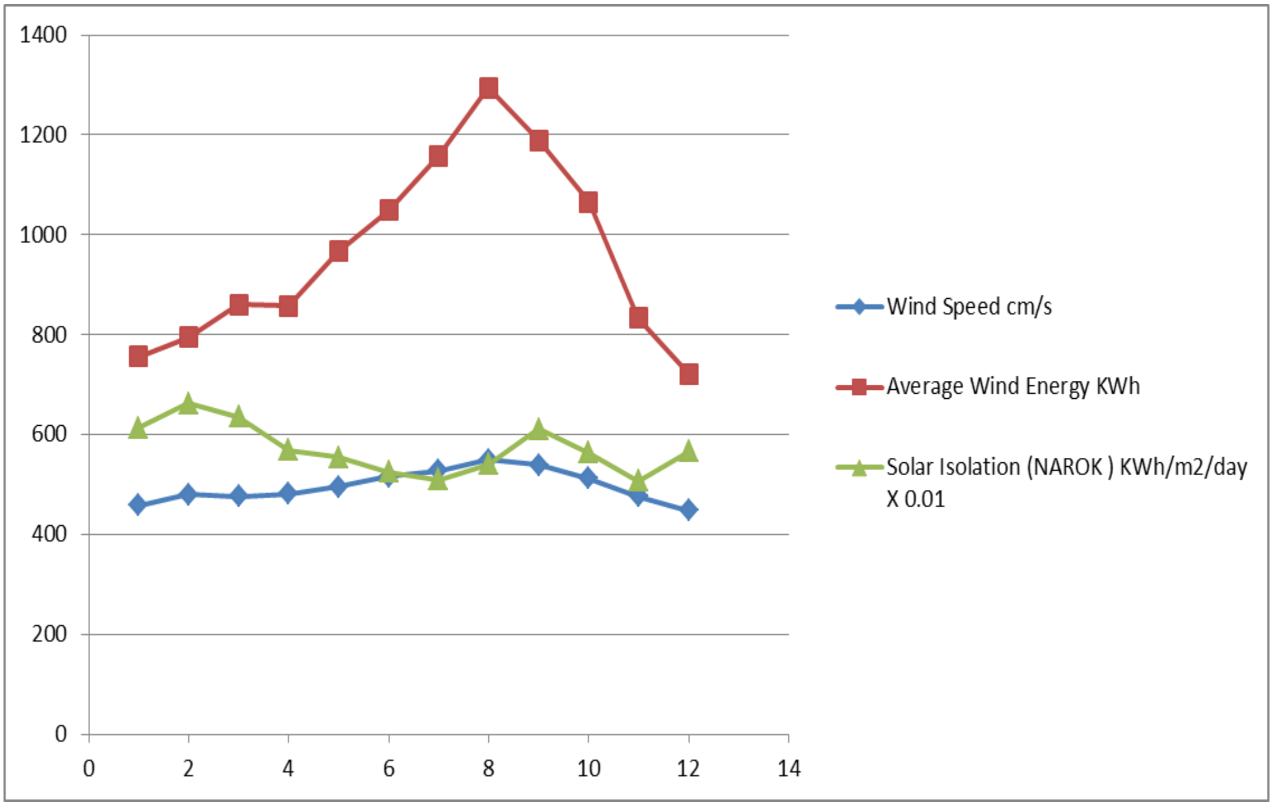

Figure 5: Average Monthly Wind Energy KWh, Wind Speed cm/s and Solar Irradiation KWh/m2/day GHI data

Source: National Renewable Energy Laboratory and Kenya Metrological.

4.3.2 PROJECTED AND ACTUAL MONTHLY FUEL CONSUMPTION AT THE SITE

Monthly fuel consumption was obtained from the available records at the site, every time maintenance is done a data sheet is filled out and a copy of the data sheet is left at the site. These helped the researcher compile the annual fuel consumption. Figure 6 presents the monthly fuel consumption at the Safaricom BTS site in Sekanani. It is evident from the data that the fuel consumption differed each month. The month of February had the highest fuel consumption and highest generator operation hours, while the month of June had the lowest fuel consumption and generator operation hours. June is the month with high wind speeds and low solar isolation and therefore more power charge to the batteries from wind can take longer hours in day and night hours while solar only prevails during the day. February and September have lower wind speeds but higher solar isolation but experience higher fuel consumptions and longer generator operation hours. This due to shorter hours of charge compared to periods with higher wind speeds.

With HOMER projections, fuel consumed by the Diesel Gen set was highest during the months of January and December which was 195 liters for both months.

During the months of February, July and August fuel consumptions were 142, 147 and 160 litres respectively as portrayed in Figure 6.

Actual fuel consumption shows that February has the highest fuel consumption values of 2000 liters which is an exact opposite of HOMER values. There was further reduction of consumption to the month of June when the lowest fuel consumption of about 480 liters was experienced. Again there is a steady rise in consumption to September of 1000 liters and a drop in October to 480 liters. November and December experience higher fuel consumptions which show a little conformance with the HOMER values. This difference between the HOMER and Actual values can also be attributed to environmental factors and fuel losses on transit as claimed by the Safaricom CEO.

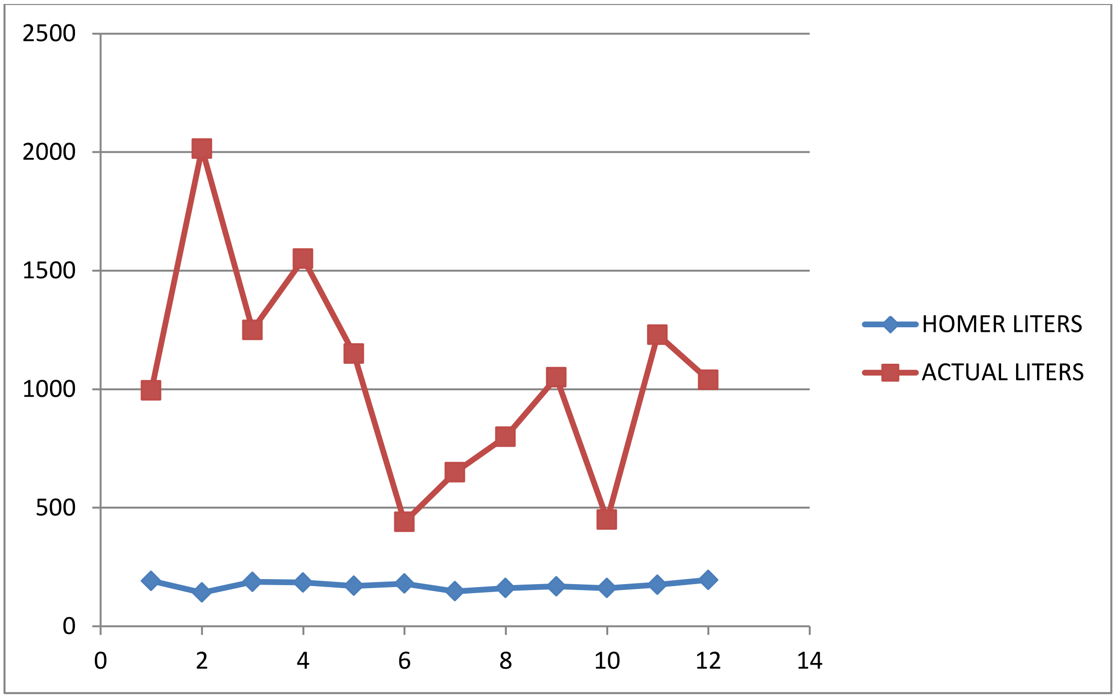

Figure 6: Monthly fuel consumption actual and Simulated from HOMER.

Source: Monthly Safaricom maintenance records

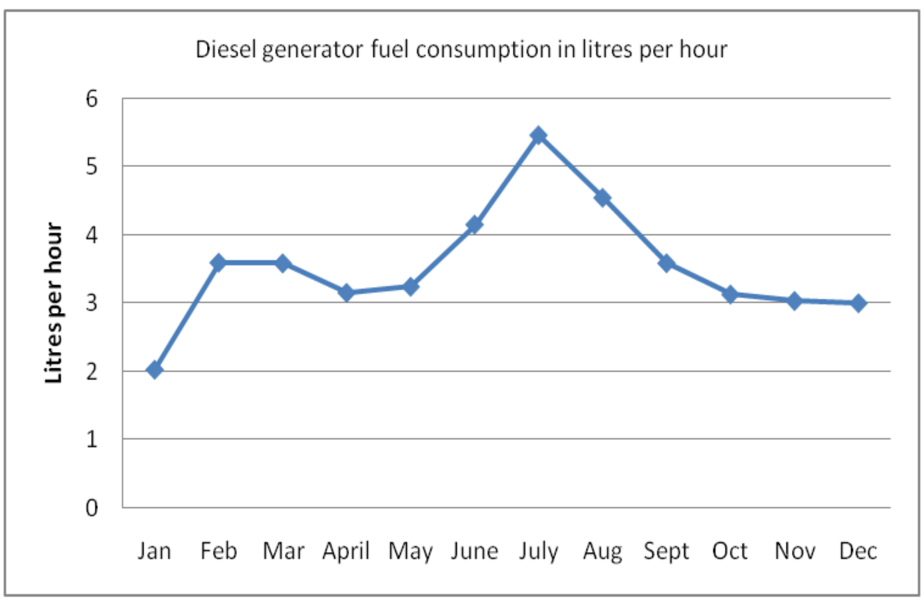

Figure 7: Diesel generator fuel consumption in liters per hour.

Source: Data available at the site

Table 1 gives the manufacturer's fuel consumption rating of the engine.

Table 1: Manufacturer fuel consumption rating of the engine

	1500 rev/min		1800 rev/min		3000 rev/min	
	L/kWh	L/hr	L/kWh	L/hr	L/kWh	L/hr
At Standby Power	0.305	6.2	0.303	7.3	0.305	10.4
At Prime Power	0.292	5.4	0.294	6.4	0.310	9.5
At 75% of Prime Power	0.292	4.0	0.297	4.8	0.323	7.5
At 50% of Prime Power	0.319	2.9	0.323	3.5	0.376	5.8

Reading from the generator meter reading indicated that it did 3840 hours which proves the fact that the generator was running at 50% of its prime power of about 3.3 liters per hour having consumed a total of 12,620 liters yearly.

At 50% prime power the generator uses an average of (.319+.323+.376)/3 = 0.34 liters to generate 1KWh of power and therefore for actual annual power that could be generated by the generator consuming 12,620 liters is about 37.2 MWH.

The annual requirement of power from the generator in this hybrid architect is about 6 MWH and therefore only about 2000 liters of diesel will be consumed on annual basis.

Diesel charging hours =3840 hours

Simulated annual energy requirement from diesel generator = 6 MWH

The recommended size of the prototype generator therefore should

be = 6 x 1000/3840 = 1.56 kVA approximately 1.6 kVA

Figure 7 shows a critical look at the data on the site, which reveals that the diesel engine at the site would consume between 2.02 litres per hour and 5.5 litres per hour. The Perkins Engine 400 series at the site has the capacity to consume up to 10.4 litres per hour, on maximum load as shown in Table 1. It is apparent that the engine is not put to maximum capacity, possibly due to the existence of the other sources of renewable energy. May be an engine with a smaller capacity could as well serve the purpose. This can also be explained by Figure 6 where there is a big intermittent fuel consumption differences between the expected and the actual. The HOMER graph indicates higher fuel consumption in January, which is expected because of low wind speeds.

4.4 ENERGY CONSUMPTION OF BTS

The installed BTS at the Sekanani site is the modern Huawei's fourth generation with one cabinet and 2000W power consumption. This translates to 2 kW X 24 X 365 = 17.52 MWH annually. It is among the latest BTS's with very economical energy consumption properties.

4.4.1 TOTAL ANNUAL ENERGY CONSUMED

Total annual energy demand is therefore the energy to run the BTS and its auxiliaries and the energy to have the batteries fully charged. The main power requirement annually is therefore 17.5 MWh .

4.5 ENERGY PRODUCTION

4.5.1 PHOTO-VOLTAIC ENERGY PRODUCTION

The power from the photovoltaic cell was calculated by HOMER, using the following equation to calculate the amount of energy produced:

$$ESPV = YSPV \times PSH \times fSPV \quad \text{.........} (1)$$

Where YSPV is the rated capacity of the SPV array (kW) and PSH is a peak solar hour which is used to express solar irradiation in a particular location when the sun is shining at its maximum value for a certain number of hours. Because the peak solar radiation is 1 kW/m^2, the number of peak sun hours is numerically equal to the daily solar radiation in kWh/m^2 and fSPV is the SPV derating factor (sometimes called the performance ratio), a scaling factor meant to account for effects of dust on the panel, wire losses, elevated temperature or anything else that would cause the output of the SPV array to deviate from the expected output under ideal conditions. In other words, the derating factor refers to the relationship between actual yield and target yield, which is called the efficiency of the SPV.

Table 2 below illustrates the energy production from wing, solar and diesel generator. The total energy produced annually from the photovoltaic panels is 20.83 MWH.

Table 2: Monthly energy produced from the different sources

	WIND ENERGY PRODUCTION	**SOLAR PVC PRODUCTION**	**DIESEL GEN PRODUCTION**	**DIESEL GEN FUEL**	**TOTAL ELECTRICAL LOAD**	**AVERAGE WIND SPEED**
	kWh	**kWh**	**kWh**	**Litres**	**kWh**	**Cm/s**
JANUARY	756.25	1794.76	507.01	191.66	1470.25	458
FEBRUARY	795.32	1757.54	376.97	142.54	1310.96	480
MARCH	860.22	1929.22	488.48	187.5	1524.69	476
APRIL	857.11	1720.46	490.36	184.98	1455.68	481
MAY	966.92	1709.12	449.74	170.29	1454.7	495
JUNE	1048.44	1612.35	472.56	180.01	1451.88	516
JULY	1158.16	1649.04	382.64	147.46	1476.11	528
AUGUST	1293.78	1741.39	422.27	160.9	1539.32	550
SEPTEMBER	1189.34	1813.04	434.78	168.53	1461.73	539
OCTOBER	1065.89	1798.18	419.32	161.16	1460.42	512
NOVEMBER	833.61	1593.94	465.86	175.34	1428.12	476
DECEMBER	721.44	1707.58	519.71	195.34	1488.14	448
TOTALS	***11546.48***	***20826.62***	***5429.7***	***2065.71***	***17522***	

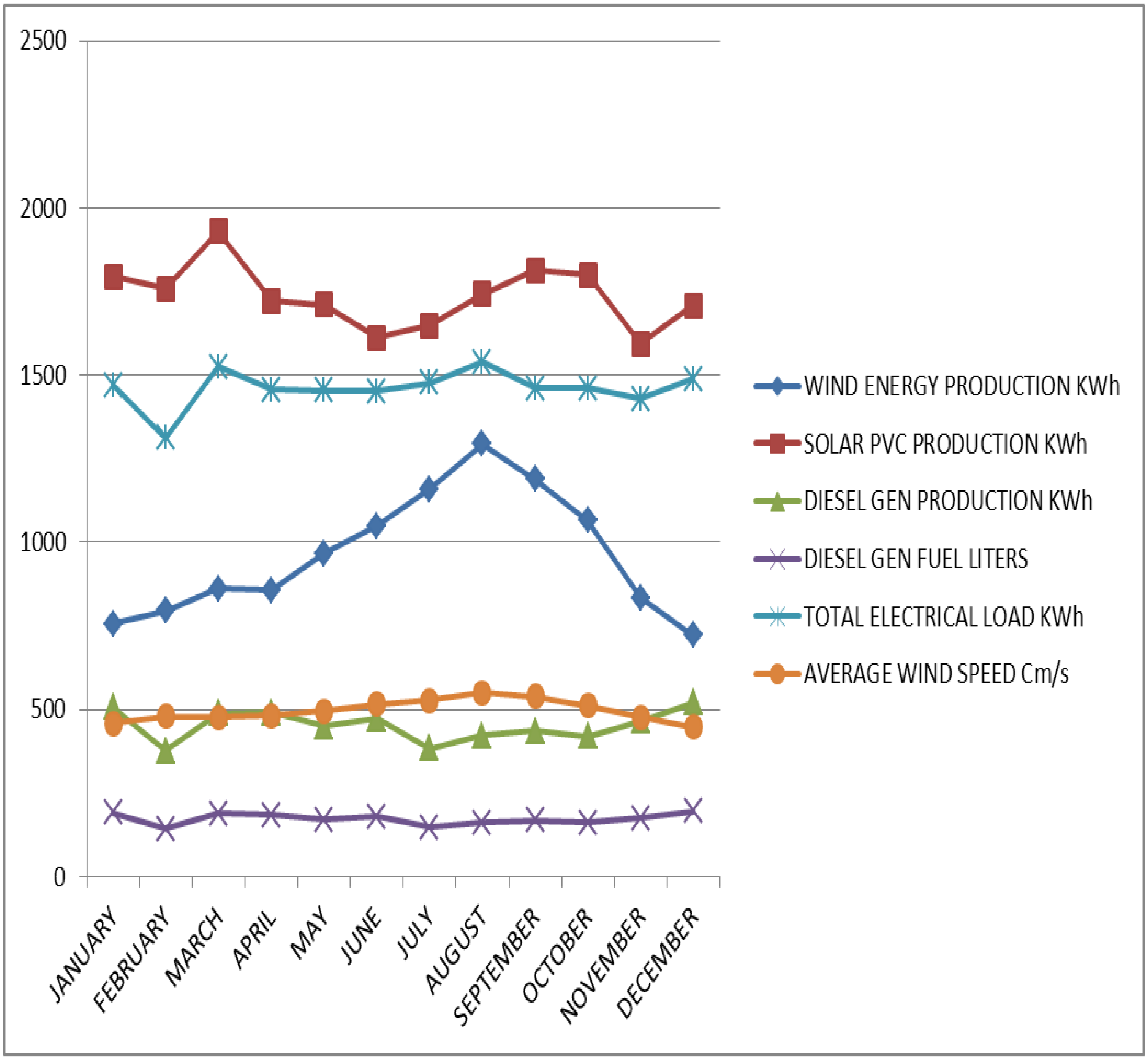

Figure 8: Graph for average monthly wind speed (cm/s), wind energy production (kWh), solar PVC energy production (kWh), diesel generator energy production (kWh), diesel generator fuel consumption (liters), and total BTS electrical load demand (kWh)

It is evident from Figure 8 that as wind speed rises the energy generation by the diesel decreases. Low wind speed in February is countered with higher energy production from the Genset and also higher wind speed in August is countered with low energy production from the Genset. Low wind speed in December is countered by higher energy production from the Genset. There is Solar energy production throughout the year with higher values experienced in March-April. It is also interesting to note that the demand of the BTS is associated with the solar irradiation, the higher the solar irradiation the higher the demand of the BTS. This might be so because of high demand of energy for cooling of the BTS. Highest wind energy production is associated with the higher demand of energy by the BTS and higher solar irradiation in August-September months of the year. August is also a holiday season and there are a lot of tourists in the region during this time and thus high demand on the communication equipment BTS.

4.5.2 WIND TURBINE ENERGY PRODUCTION

As evident in the above Table 2 the months of July, August and September witness high production of power from wind turbine at 1158.16, 1293.78 and 1189.34 kWh, respectively, that coincides with high wind speeds during the same period of average speeds 5.28, 5.5 and 5.39 m/s respectively for the months of July August and September. The total annual production from the turbine is 11.55 MWH which is rather below the demand of the BTS 17.52 MWH. This shows that it may not be possible to use wind turbine alone, it must be hybridized either with Solar PV, Diesel generator or both.

4.5.3 DIESEL ENGINE ENERGY PRODUCTION

The records at the Sekanani site revealed that the total amount of fuel consumed throughout the year was 12,620 litres. With the standards of the generator this fuel could generate about 37.2 MWH of power. This was able to bridge the gap of the energy produced from solar and wind generator only during the low seasons of the green energies. But in the final run 32.38 MWH produced from the wind and solar is adequate to supply the 17.5 MWH required of the BTS and its accessories. Only the solar panels and wind turbines are capable of producing sufficient power for the BTS demand. The generator set is only to compensate for the shortfalls due to seasons and complete absence of solar daily.

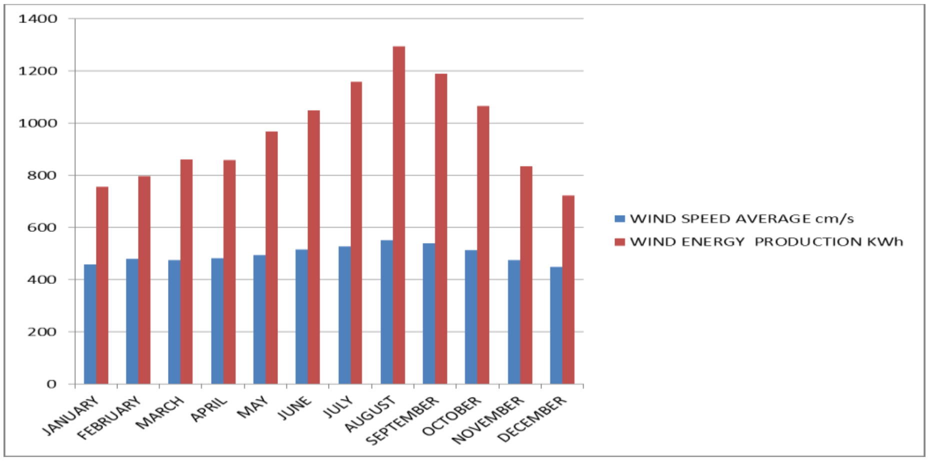

Figure 9 : Average wind speed (cm/s) and wind turbine energy production (KWh)

4.5.4 SIMULATED DIESEL ENGINE ENERGY PRODUCTION

The total energy produced from the diesel generator set for the year was 5.38 MWH. The month of December contributed the highest from the diesel generator set at 519 kWh, since there are very low wind speeds during this period therefore diesel generator therefore would work more. Figure 10 illustrates monthly power produced and the diesel fuel consumed by the diesel generator set. Very high solar irradiance is experienced during February and therefore this compensates for the low fuel, though wind speeds are also very low.

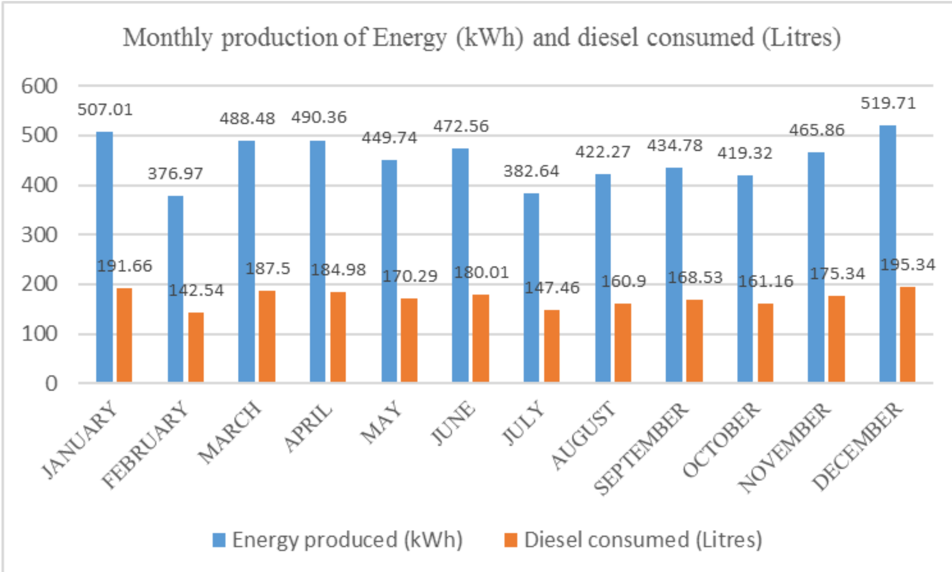

Figure 10: Monthly Energy produced and diesel consumed

4.5.5 TOTAL HYBRID ENERGY PRODUCTION

The total hybrid energy produced at Sekanani therefore was the energy from wind, solar and diesel engine. This translates to (Solar panels 20.83 MWh + Wind turbine 11.55 MWh + Diesel Engine 5.38 MWh) = Total 37.76 MWh against the net requirement of the BTS and the storage batteries annual demand of 17.50 MWh. The amount of energy generated from green sources in the hybrid per annum is 32.38 MWh which should be more than adequate to satisfy the BTS and its accessories demand which is 17.50 MWh. The diesel generator is just supplementing the energy demand by only 5.38 MWh annually.

This therefore shows an over capacity of the energy produced from the sources of 37.75- 17.50 MWh = 20.26 MWh annually.

4.6 THE RETURN ON INVESTMENT

The Sekanani BTS operates on wind, solar and one diesel generator and therefore the return on investment for the site is majorly a comparison between the capital cost of a wind turbine, solar panels and the single generator against both capital and operating costs for running two generators. Although diesel generators remain the primary choice for powering off-grid base stations, the ROI keeps changing with the new fuel prices. Additionally, there is a move by the government to introduce incentives for electricity generation from renewable sources. The number of solar and wind powered base stations is therefore expected to grow appreciably due to growing government incentives and fall in the cost of solar and wind turbine technology.

Although diesel generators still remain the single most important 'backup' power source for sites where grid power is unreliable, in the case of a poor-grid deployment, the use of renewable power sources to back up the grid will be less important than for off-grid locations, because the cheapest and simplest solution may be to simply use battery backup power.

The choice of a suitable single or hybrid system was made from simulation and optimization results from HOMER using costing and sizing as the optimization variables and compared to a photovoltaic-wind-diesel-battery system. These results have been presented in Table 3. It can be seen from the results that a system without a renewable energy component is the most expensive, while a PV/Wind/Battery hybrid can meet the demand cost effectively. For the high demand level of 254kWh/day, a diesel generator-only system is more reasonable in terms of cost than a renewable energy-only system. However, the life cycle costing of a diesel generator-only system may be improved by adding at least one renewable source with a battery.

Table 3: Initial cost, operating cost, and total NPC of Genset energy systems

Parameter	Diesel
Initial Cost	$310,360
Operating Cost	$1,756,634
Total NPC	$22,766,034

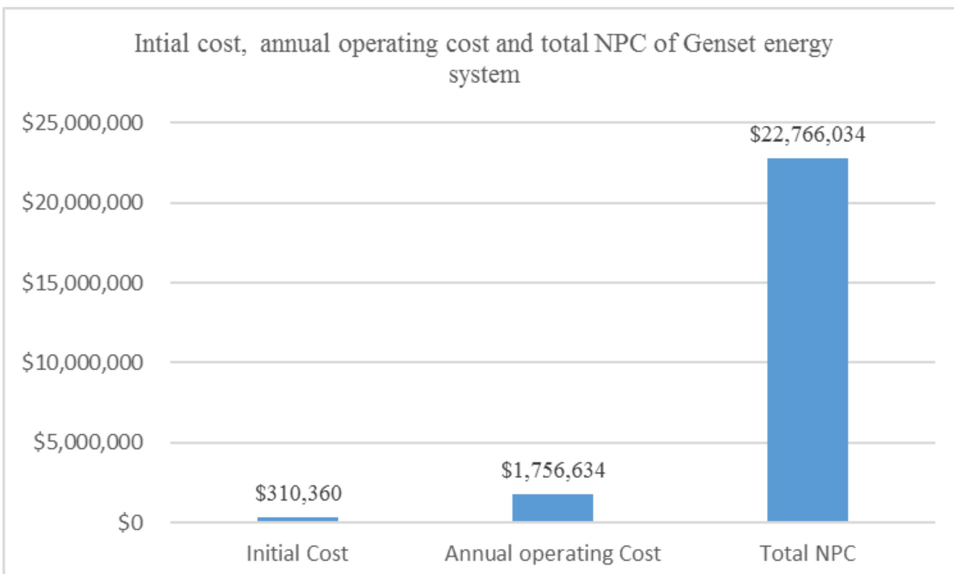

Figure 11: Initial cost, annual operating cost, and total NPC of Genset energy systems

For diesel generator alone therefore:

Total simulated energy produced annually reference Table 7. = 34.81MWH

Net Present Cost (NPC) of production = $22,766,034

Cost per kWh produced = $22,766,034/ 34.81 x30 MWH = $21.8/MWH

Table 4: Simulated NPC values of Hybridized Solar PV and Wind only. Cost summary Cash flow compares Economics electrical Renewable Penetration Generic 1kWh Li-Ion Generic flat plate PV system Converter Emissions.

COMPONENT	CAPITAL($)	REPLACEMENT($)	O&M($)	FUEL($)	SALVAGE($)	TOTAL($)
Generic 1kWh Li-Ion	1,455,000.00	617,318.42	313,492.25	0.00	116,185.56	2,269,625.12
Generic flat plate PV	5,330,823.53	0.00	229,714.39	0.00	0.00	5,560,537.92
System Converter	127,575.41	54,126.91	0.00	0.00	19,187.23	171,515.09
System	6,913,398.94	671,445.33	543,206.65	0.00	126,372.79	8,001,678.13

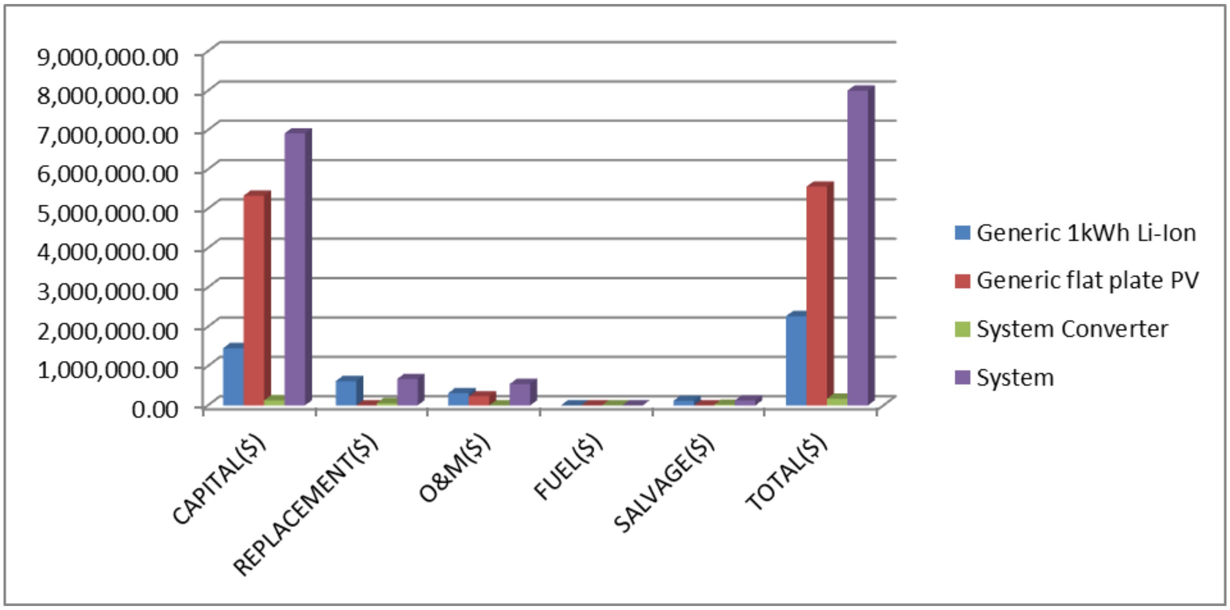

Figure 12: Graph of the Simulated NPC of the Solar PV hybrid with the Wind turbine

System Architecture : Generic flat plate PV (1776941177kW) HOMER Cycle Charging

Generic 1kWh Li-Ion (2425 strings)

System Converter (425 kW)

Total NPC: $8,001,678.00

Levelized COE: $0.7001

Operating Cost $84,183.16

Wind turbine and solar PV are capable of generating 11.55MWh and 20.83 MWh annually respectively and therefore they have a combined annual generation of 32.38 MWh.

With an NPC of $8,001,678.00 with 30 years life span

Cost per MWH Produced = $8,001,678.00/ 32.38 x 30 = $8.24/MWH

Table 5: Simulated NPC of the Hybridized Solar PV , diesel Generator and Wind turbine

COMPONENT	CAPITAL ($)	REPLACEMENT ($)	O&M ($)	FUEL ($)	SALVAGE ($)	TOTAL ($)
10kW Fixed Capacity Genset	5,000.00	-	27,147.00	2,585.35	(1,058.05)	6,798.77
Generic 1kWh Li-Ion	1,455,000.00	617,318.42	313,492.26	-	(116,185.56)	2,269,625.12
Generic flat plate PV	5,172,915.90	-	222,909.86	-	-	5,395,825.76
System Converter	1,028.93	45,061.67	-	-	(8,481.06)	142,789.54
System	6,739,124.83	662,380.09	536,673.59	2,585.35	(125,724.67)	7,815,039.19

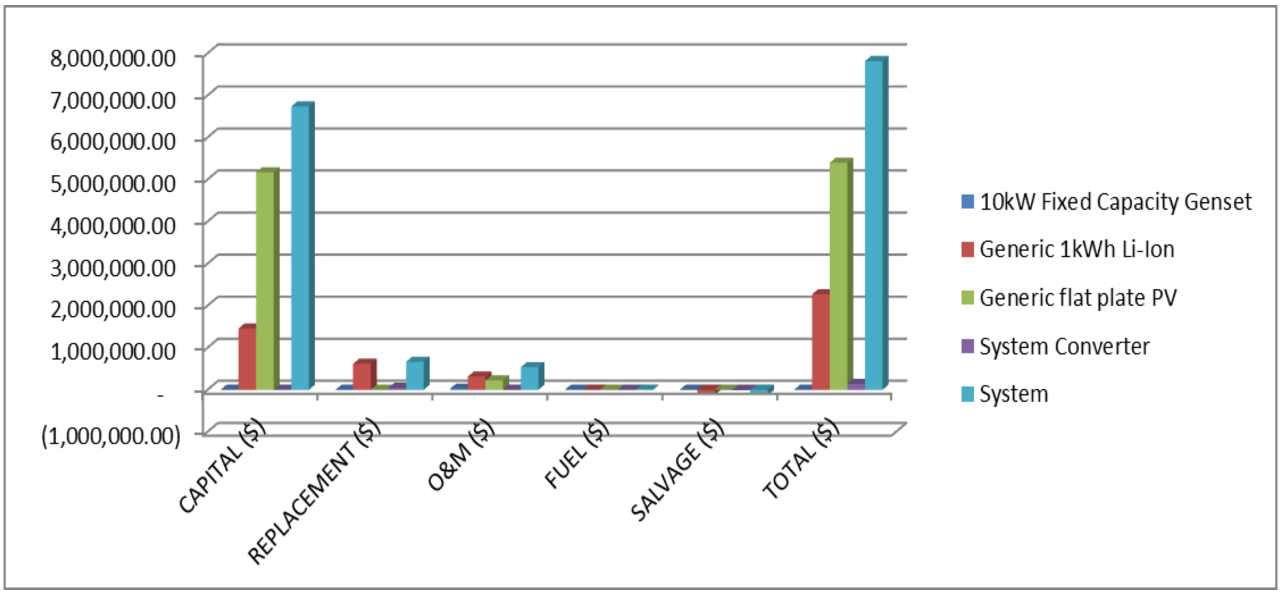

Figure 13 Graph of the Simulated NPC of Hybridized Solar PV, Diesel Generator and Wind turbine

System Architecture : Generic flat plate PV (1724305300 kW)
10kW Fixed Capacity Genset (10 kW) HOMER Cycle Charging
Generic 1kWh Li-Ion (2425 strings)
System Converter (354 kW)

Total NPC: $7,815,039.00
Levelized COE: $0.6837
Operating Cost $82,226.89

Wind turbine and solar PV and Diesel Generator are capable of generating 11.55MWH and 20.83 MWH and 5.43MWH annually respectively and therefore they have a combined annual generation of 37.81 MWH.

With an NPC of $7,815,039.19 with 30 years life span

Cost per MWH Produced = $7,815,039.19/ 37.81 x 30 = $6.89/MWH

Table 6: NPC for various Hybrid combinations

ARCHITECTURE	NPC $/MWH
GENSET ALONE	21.8
SOLAR PV & WIND TURBINE HYBRID	8.24
SOLAR PV, WIND TURBINE & GENSET HYBRID	6.89

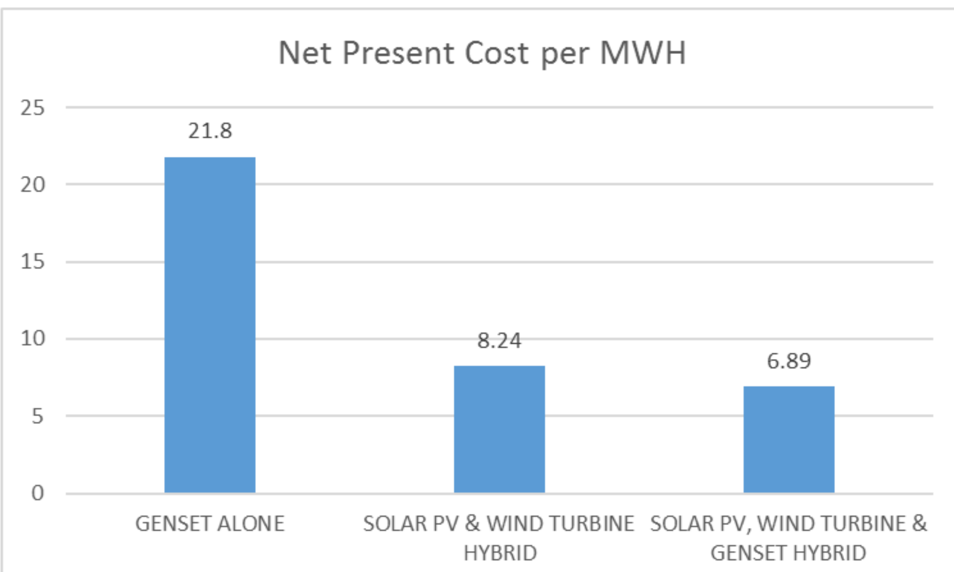

Figure 14: NPC Values for various Hybrid combinations.

4.6.1 COMPARISON BETWEEN DIESEL ENGINE AND A HYBRID SYSTEM OF PV/WIND/DIESEL

Figure 15 illustrates a comparison between a diesel engine and hybrid systems of PV, wind and diesel, PV and Wind and PV alone. It is worth noting that even though the initial installation cost of the hybrid system is higher than the installation of a diesel engine in the long run the cost of operating a hybrid system is lower than the cost of running a diesel system. The initial cost of installing a diesel engine is lower than a hybrid system. The Net Present Cost per MWH of hybrid system of PV, wind and diesel is three times lower than a diesel engine system. As can be shown in Figure 15, the NPC per MWH of the hybrid is $6.89 while that of genset is $21.80 which gives a ratio of 1:3 in respective costs. The NPC per MWH for the hybrid without the Genset is also slightly costlier than the triplet system.

PV alone is also more costly than any of the hybrid combinations. This can be attributed to the huge initial cost that is incurred to have as many PV cells as possible and the initial cost of the storage system is also very high. Genset alone high cost can also be attributed to the number, which has to be more than one, and therefore automatically high maintenance cost, high fuel cost and even the size of the location.

Table 7: (HOMER) Annual Hybrid Energy (Wind & Genset) only, (Solar PV & Genset) only and Non-Hybrid Genset only.

	HYBRID ENERGY	HYBRID ENERGY	HYBRID ENERGY
	WIND & GENSET-battery	Solar & GENSET-battery	GENSET-battery only
	PRODUCTION	PRODUCTION	PRODUCTION
	KWh	KWh	KWh
JANUARY	3210.59	3406.79	2920.15
FEBRUARY	2854.04	3439.86	2869.15
MARCH	3114.59	3604.35	2924.18
APRIL	3041.35	3404.01	2869.15
MAY	3165.85	3409.33	2924.18
JUNE	3289.09	3319.63	2869.15
JULY	3505.39	3356.63	2924.18
AUGUST	3606.58	3438.61	2924.18
SEPTEMBER	3617.64	3476.31	2869.15
OCTOBER	3428.98	3489.88	2924.29
NOVEMBER	3104.28	3287.28	2869.15
DECEMBER	2931.83	3395.46	2924.18
TOTALS	38870.21	41028.14	34811.09

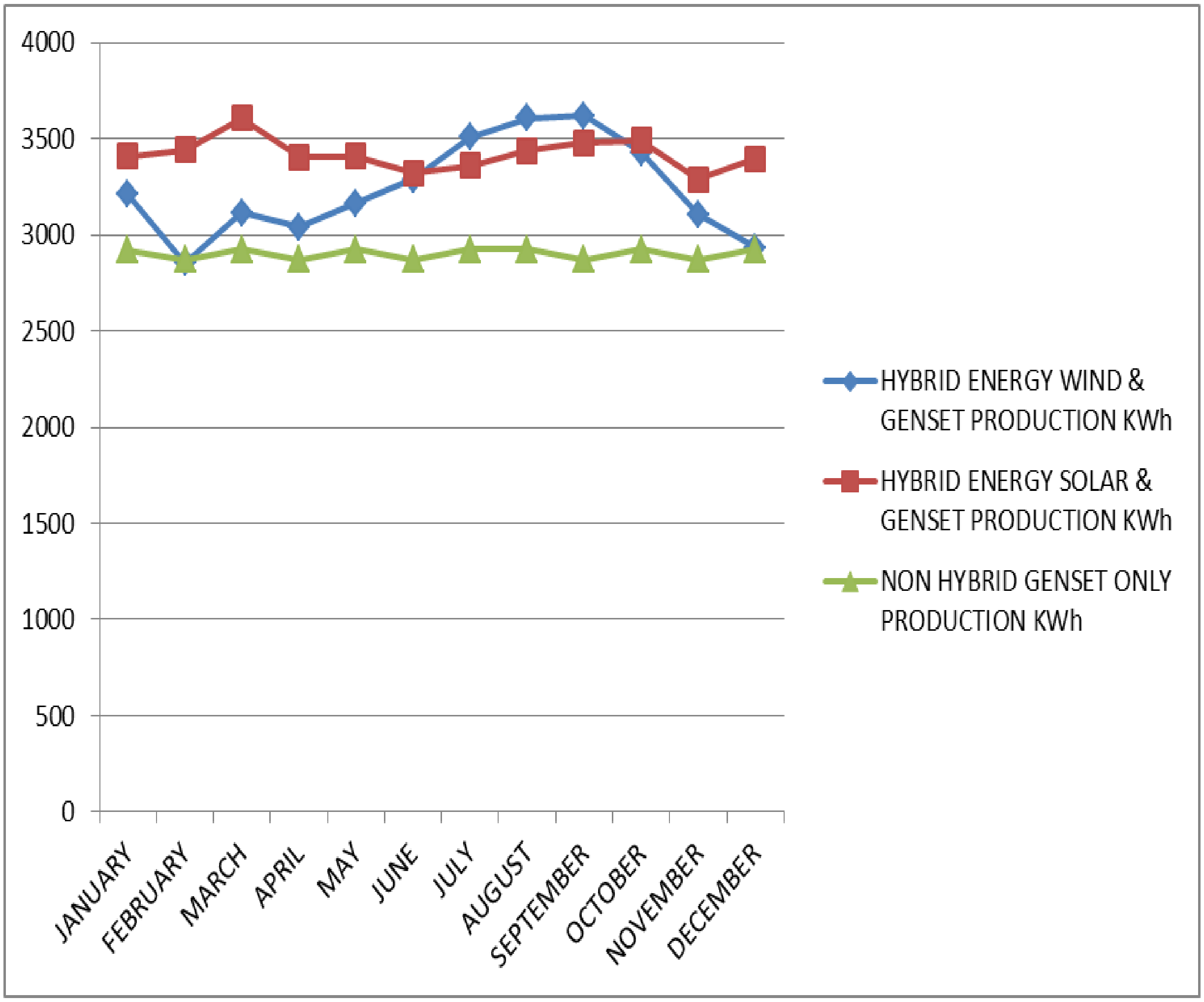

Figure 15 Graph for HOMER Simulated Hybrid Energy (Wind & Genset only) kWh, (Solar PVC & Genset only) kWh and Genset kWh only,

From the records available on-site, it was established that the cost of fuel is the single factor contributing most to the recurrent expenditure. Discussions with the staff established that other items of recurrent expenditure include cost of leasing the premises and the hiring of security personnel at the site.

4.7 REGULATIONS AND STANDARDS TO BENCHMARK THE VARIOUS ALTERNATIVE ENERGY TECHNOLOGIES

The study sought to establish the regulations and standards in place for benchmarking various alternative energy technologies. It was established that Kenya has made strides in putting in place regulations and standards to benchmark the technologies. Renewable sources of energy i.e. solar and wind energy have been addressed in a policy framework set out in Sessional Paper Number 4 of 2004.This energy policy outlines the broad objectives of wind and solar resources andrecognizes the importance of the two renewable energy sources and it has therefore provided incentives for the large scale utilization of the two largely untapped energy resources.

Vision 2030 encourages increased power production as a support for the economic pillar. Kenya intends to use independent power producers with a focus on renewable energy sources. Already the exploitation of geothermal energy is underway and it now accounts for over 50% of the electricity consumed in Kenya. Development of solar and wind power projects are already under way. These include Lake Turkana wind power project and Kipeto power project.

The new energy act enacted after the promulgation of the Constitution of Kenya 2010 recognizes the existence of renewable energy and other forms of energy such as nuclear energy and coal. The new Energy Act creates a number of regulatory authorities under the umbrella of the Energy Regulatory Authority, including the Energy and Petroleum Tribunal, the Rural Electrification and Renewable Energy Corporation, the Energy and Petroleum Institute (successor to the Kenya Nuclear Electricity Board) and the Renewable Energy Resource Advisory Committee.

The new Constitution of Kenya, 2010 puts in place the community benefit sharing and public participation. The Government of Kenya through Legal Notice 91 of 2015 exempts interest on loans advanced from foreign sources from tax, provided the funds are utilized for investing in infrastructure. The primary aim of the Kenyan Government in granting these exemptions is to attract more investments in the energy sector for the purpose of lowering the cost of energy.

4.8 ENVIRONMENTAL IMPACT OF WIND POWER

Harnessing power from wind is one of the most sustainable ways to generate electricity as it produces no toxic pollution or global warming emissions. Wind is also abundant, inexhaustible, and affordable, which makes it a viable and large-scale alternative to fossil fuels.

The land use impact of wind power facilities varies substantially depending on the site: wind turbines placed in flat areas typically use more land than those located in hilly areas. However, wind turbines do not occupy all of this land; they must be spaced approximately 5 to 10 rotor diameters apart (a rotor diameter is the diameter of the wind turbine blades). Thus, the turbines themselves and the surrounding infrastructure (including roads and transmission lines) occupy a small portion of the total area of a wind facility.

The impact of wind turbines on wildlife, most notably on birds and bats, has been widely documented and studied. The birds sometimes collide with the turbines and die. However, these are isolated cases.

Sound and visual impact are the two main public health and community concerns associated with operating wind turbines. Most of the sound generated by wind turbines is aerodynamic, caused by the movement of turbine blades through the air. There is also mechanical sound generated by the turbine itself. Overall sound levels depend on turbine design and wind speed.

When it comes to aesthetics, wind turbines can elicit strong reactions. To some people, they are graceful sculptures; to others, they are eyesores that compromise the natural landscape. Increasing the number of wind turbines to boost power supply may be born with a lot of counter productivity not to mention space availability and therefore may not be an instant viability of hybridization supporter in this study.

4.9 THE KEY PLAYERS IN THE PROVISION OF SOLAR AND WIND ENERGY TECHNOLOGIES IN THE TELECOMMUNICATIONS SECTOR IN KENYA

In an effort to establish the key players in the provision of solar and wind energy technologies in the telecommunication sector in Kenya the study looked at both the government and private companies.

The main actors in the energy sector are the government, quasi-governmental specialized organization, the private sector and regulator. The Kenya Energy regulatory Commission is just at the forefront in the regulation of energy; there are a number of firms doing the Energy Audit in the country. The government through the Ministry of Energy and Petroleum is responsible for policy formulation and articulation and in providing an enabling environment for all stakeholders. Over the years the government through the ministry has overseen the least cost power development planning process and directs the rural electrification programme and planning. In the power sector Kenya Power and Lighting Company KPLC has been distributing and retailing power while KenGen, which is 70% owned by government while the public owns the rest, dominates power generation.

The private sector is more pronounced on the petroleum sub-sector which was fully liberalized in 1994. The government-owned Kenya pipeline company delivers the bulk of the white fuels to major consumer centers of Nairobi, Nakuru, Eldoret and Kisumu.

In the power sub sector a number of independent power producers (IPPs) are active in power generation mainly using thermal power systems and one IPP is engaged in geothermal power generation in the Rift Valley. The Energy Regulatory Commission was created recently with the enactment of the Energy Act in 2006 and is responsible for regulatory and pricing processes and it is mandated by the Environmental Management Authority to be the leading institution on energy and environment matters.

Safaricom in an effort to hybridize, partnered with Winafrique Technology Ltd (WTL). Winafrique Technologies Ltd was formed as an integrated renewable energy resource company in August 2001, with the objective of exploring the vast renewable energy market in East and Central Africa. The company's main emphasis has been on wind-solar hybrid energy systems.

Winafrique actively participates in the development processes of all the projects it undertakes. This will normally be in conjunction with corporate bodies, Governments, NGO's and various other institutions. The key objective in their participation is to recommend green energy solutions that are not only sustainable, but are environmentally friendly and make good economic sense.

The company has successfully applied its renewable energy systems and powering equipment in various sectors, telecommunication, school lighting and ICT, water desalination, irrigation for farming and making clean water in households. The main solution categories at Winafrique are:

- Hybrid remote alternative power systems;
- Wind power solutions;
- Solar power solutions;
- Water pumping solutions;
- Power enhancing solutions; and
- Energy storage solutions.

Winafrique states that they represent some of the most reputable companies associated with renewable energy products. Some of the products include:

- Wind Turbines & Towers – Bergey from Bergey Wind Company U.S.A;
- Energy Storage System – VRB-ESS from VRB Power Systems Canada;
- Solar Panels- Sanyo from Sanyo (Pty) South Africa;
- DC Generators- Polar from Polar Power U.S.A;
- Power Inverters- Outback from Outback Power systems U.S.A;
- Power Enhancers- from Winafrique Technologies Ltd Kenya;
- DC Air conditioners- from DC Air Co, Netherlands; and
- Tyco Rectifiers- From B+W Electronics Germany.

Among successful projects carried out by Winafrique include over 70 installations of Wind, Solar and Diesel hybrids to provide power to remote GSM base stations for telecommunication companies. WTL has also carried out two wind/solar hybrid solutions for International Committee of the Red Cross for water desalination plants in Kizingitini and Mtangawanda Islands in Lamu on the Kenyan coast.

Other key players include Philafe Engineering Limited (PEL). Philafe Engineering Limited is an Electrical/Electronic Engineering and ICT company specializing in design, fabrication, system implementation, and maintenance. They offer post implementation support services in the fields of electrical/electronic engineering, ICT engineering, building construction and civil engineering. Established in 1995,the company provides quality services to varied clients in the power utility industry, both public and private, mobile communication service providers and corporate firms providing services in commercial, industrial and agricultural establishments.

Philafe's service portfolio includes:-

- Electrical power systems development and installation
- GSM, BTS & MSR facilities power and transmission systems maintenance
- Fiber optic plant networks and structured cabling solutions implementation
- Hybrid power systems implementation
- Green (solar/wind) power systems implementation
- Telecommunications solutions implementation
- Office automation and security systems implementation
- Building construction and civil engineering

Huawei Technologies Co. Ltd.: is a Chinese multinational networking and telecommunications equipment and services company headquartered in Shenzhen, Guangdong. It is the largest telecommunications equipment manufacturer in the world, having overtaken Ericsson in 2012.

Huawei was founded in 1987 by RenZhengfei, a former engineer in the People's Liberation Army. At the time of its establishment Huawei was focused on manufacturing phone switches, but has since expanded its business to include building telecommunications networks; providing operational and consulting services and equipment to enterprises inside and outside of China; and manufacturing communication devices for the consumer market.

Huawei is organized around three core business segments:

1. Telecom Carrier Networks: building telecommunications networks and services
2. Enterprise Business: providing equipment, software and services to enterprise customers, e.g. Government Solutions etc.
3. Devices: manufacturing electronic communications devices

Huawei offers a variety of network technologies and solutions to help telecommunications operators expand the capacity of their mobile broadband networks. Huawei’s core network solutions offer mobile and fixed soft switches, plus next-generation home location register and Internet Protocol Multimedia Subsystems (IMS).

4.10 SUMMARY OF THE KEY FINDINGS

The return on investment for the site was majorly a comparison between the capital cost of a wind turbine, solar panels and the diesel generator against both capital and operating costs for running diesel generators alone.

The simulation results showed that a system with no renewable energy is the most expensive, while a PV/Wind/Battery can meet the demand cost effectively. It further illustrated that the cost of a PV/Wind/Battery hybrid system is three times cheaper than the cost of running standalone diesel generators. The deployment of solar and wind energy even though cheap, sometimes depend on weather conditions. To work effectively, a backup generator is therefore ideal.

Some of the hindrances to deployment of renewable energy include:

- The traditional duplicity and distortion of the energy prices due to hidden subsidies especially in the power sector.
- Absence of a suitable legal and regulatory framework.
- Lack of institutional support to promote widespread use of wind energy; some of which the new Energy Regulatory Commission is yet to address.
- High initial capital costs of the systems despite gradual reduction of the indirect taxes by the Government over the years with no significant price reductions.
- A further lack of awareness of potential opportunities, market niche for electricity production and the economic benefits offered by wind energy technology.
- Lack of appropriate credit and financing mechanisms to facilitate acquisition of wind technology by the rural population is a hindrance.

- Additionally, associated capital flight in acquiring renewable energy especially solar and wind energy, where up to 90% of the costs go to suppliers abroad is also a hindrance.
- Finally, lack of necessary infrastructure to support the technology and the traditional planning mechanism exclusively based on conventional power production systems in LCPD.

The rapid changes in the energy sector necessitated the repeal of the Energy Act 2006 and the Geothermal Resources Act, 1982 and the introduction of a new act that consolidated the laws relating to energy. The Government has recognized the need to review the existing legal regime to facilitate growth. The new act also aligned the legal and regulatory framework of the energy sector with the Constitution of Kenya, 2010, with attempts to clarify the roles of the National and County Governments in relation to energy. The Energy Act, unlike the current Energy Act, 2006, recognizes the existence of renewable energy and other forms of energy such as nuclear energy and coal. The act permits production and distribution so long as it is not above 3 MW.

All energy sources have some impact on our environment. Fossil fuels do more harm than renewable energy sources by most measures, including air and water pollution, damage to public health, wildlife and habitat loss, water use, land use, and global warming emissions.

There are little potential environmental impacts associated with solar power when the system is small. However in large scale production there could be issues of land use and habitat loss, water use, and the use of hazardous materials in manufacturing.

Harnessing power from the wind is one of the cleanest and most sustainable ways to generate electricity as it produces no toxic pollution or global warming emissions. Wind is also abundant, inexhaustible, and affordable, which makes it a viable and large-scale alternative to fossil fuels.

The main actors in the energy sector are the government, quasi-governmental specialized organizations, the private sector and regulator. The government through the ministry of energy is responsible for policy formulation and articulation and providing an enabling environment for all stakeholders. Over the years the government through the ministry of Energy has overseen the least cost power development planning process and directs the rural electrification programme and planning. In the power sector KPLC has been distributing and retailing the power while KenGen, which is 70% owned by government while public owns the rest, dominates power generation.

Safaricom in an effort to hybridize partnered with Winafrique Technology Ltd. Winafrique Technologies Ltd was formed as an integrated renewable energy resource company in August 2001, with the objective of exploring the vast renewable energy market in East and Central Africa. The company's main emphasis has been on wind-solar hybrid energy systems.

4.11 PROTOTYPE MODEL

Based on the information gathered from the field and the recommendation of the HOMER software the least cost combination of components meeting the required load was established and a prototype model recommended. The prototype incorporated the components that would improve the energy output of the hybrid system at minimum cost.

CHAPTER 5

5.0 CONCLUSION AND RECOMMENDATIONS

Diesel powered remote BTS is most expensive, given the cost of fuel and the routine maintenance. It was further demonstrated that there was over capacity in energy production at the site. The diesel engine at Sekanani should be able to produce produced up to 37 MWH of energy annually. This was despite the annual demand load of only 17.5 MWh and not to mention annual production of 20.83 & 11.55 MWh from solar and wind turbine respectively. The simulation results reveal that only 5.38 MWh annually is needed for stand by purposes which can be realized from 2000 liters of diesel fuel.

It is further realized that the power produced from the photovoltaic cell and wind generator can run the BTS, however due to changing weather conditions it is necessary to have a backup diesel generator that would fill up the gap at any time the drop is realized.

On economic terms the Net Present Costs (NPC) of various combinations from HOMER simulations were found to be as follows:

- Genset and ancillaries NPC/kWh is $21.8/kWh
- Solar PV and Wind Turbine Hybrid and ancillaries NPC/kWh is $8.24/kWh
- Solar PV and Wind Turbine and Genset Hybrid and ancillaries NPC/kWh is $6.89/kWh

Therefore the hybrid architecture with the least net present cost is the triplet one that combines all the three sources of energy.

The simulation results showed that a system with no renewable system is the most expensive, while a PV/Wind/Battery can meet the demand cost effectively. However, it is ideal to hybridize as the supply of solar is not uniform through the day and during rainy seasons.

The space housing the equipment is small and the huge masts for the communication equipment and the wind generator further interfere with solar energy, blocking the sun as the position of the sun changes. The study therefore proposes a solar panel mounted on the roof top. This positioned on the roof top of the diesel generator house would be ideal.

5.1 RECOMMENDED PROTOTYPE

Discussion with the engineers at Safaricom revealed that the major problem at the site was the shadowing of the solar panels as is evident in Figure 1. The following prototype is recommended to address the shadowing and the limited space available, of the solar panels due to the changing positions of the sun. It is recommended that the available space on the roof of diesel engine be used to mount the solar panels. The solar array system is a feasible method of maximizing the energy received from solar radiation. In order to take care of over capacity of the system, the study also recommends a prototype diesel generator of about 1.6 kVA which can successfully satisfy the load demand at low level of fuel consumption and reduced pollution effects.

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APPENDICES

APPENDIX 1: INTRODUCTION LETTER FROM UNIVERSITY

UNIVERSITY OF NAIROBI

Department of Mechanical and Manufacturing Engineering

Telegrams: "Varsity" Nairobi
Fax: 254 020 2245566
Telephone: 254 020 318262
Extn: 28383
Email: dept-mmengineering@uonbi.ac.ke

P.O. Box 30197
GPO 00100
Nairobi
KENYA

11th December 2015

TO WHOM IT MAY CONCERN

Dear Sir/Madam,

RE: **OWINO PATRICK ODHIAMBO – F56/83720/2012**

The above named is a student at the University of Nairobi, Department of Mechanical & Manufacturing Engineering pursuing a Master of Science degree in Energy Management.

He has successfully completed part one of the proscribed Program comprising of course work and Examinations.

He's now embarking on undertaking his project titled: "Evaluation of the viability of Solar and wind hybridization of safaricom off grid global system for mobile (gsm) communication base station sites" for part two of the course.

Any assistance accorded to him will be highly appreciated.

Prof. P.M Luti
Coordinator.
Energy Management Program
Dept. of Mechanical & Manufacturing Engineering.

APPENDIX 2: NON-DISCLOSURE AGREEMENT FROM SAFARICOM

•

dated 2013

between

SAFARICOM LIMITED

AND

[•]

NON-DISCLOSURE AGREEMENT

TABLE OF CONTENTS

THIS NON-DISCLOSURE AGREEMENT(this "**Agreement**") is made the……………day of …………**.. 2013 ("the Effective Date") BETWEEN**:

1 **SAFARICOM LIMITED** a limited liability companyincorporated in the Republic of Kenya and having its principal office at Safaricom House, Waiyaki Way, Nairobi and of P.O. Box 66827-00800, Nairobi, Kenya (**"Safaricom"**) of the one part; and

2 [●] whose registered physical location is care of the [●](**"**hereinafter called **"the Student"**) of the other part.

(Each of which may be referred to as a "**Party**" and collectively as the "**Parties**")

WHEREAS

A. Safaricom is about to release certain information pertaining to [●]to facilitate a PHD Thesison[●]. (the "Purpose")

B. This Agreement is being executed in connection with the disclosure of information that will be undertaken for the Purpose set out in (A) above.

C. Safaricom has agreed to disclose the information on condition that the acknowledges he will gain access to Proprietary Information (as defined in Clause 1.3) of Safaricom and is legally bound by the terms of this Agreement, and shall maintain the confidentiality of all such Proprietary Information in accordance with this Agreement.

NOW THEREFORE, in consideration of the mutual promises and covenants made herein and for other good and valuable consideration the receipt and sufficiency of which are hereby acknowledged, the Parties, each intending to be legally bound, agree as follows:

DEFINITIONS

1.1. "**Disclosing Party**" means Safaricom Limited or any of its Parent or Subsidiary companies.

1.2. "**Receiving Party**" means the Student.

1.3. "**Confidential Information**" means all information and know-how, regardless of whether or not in writing, of a private, secret or confidential nature that relates to the business, technical or financial affairs of the Disclosing Party, its subsidiaries, affiliates, customers, potential customers, suppliers or potential suppliers, provided or disclosed to the Receiving Party or which becomes known to the Receiving Party, whether or not marked or otherwise designated as "confidential", "Confidential" or with any other legend indicating its Confidential nature. Confidential Information includes, by way of illustration and not limitation, all forms and types of financial, business, scientific, technical, economic, or engineering information, including patterns, plans, compilations, inventions and developments, products, formulas, designs, prototypes, methods, techniques, processes, procedures, computer programs and software (whether as source code or object code), documentation, technologies, plans, the Supplier's information, customer information, personnel information, research, and reports, whether tangible or intangible, and whether or not stored, compiled, or memorialised physically, electronically, graphically, photographically, or in writing. Confidential Information shall further include any such information, materials, tangible or intangible property of customers of, suppliers to or any other third party with whom the Disclosing Party does or considers doing business and who may have disclosed or entrusted such information to a Receiving Party pursuant to or in furtherance of the discussions and exchanges under this Agreement.

1.4. Confidential Information shall **not** include information that:

1.4.1. has become public knowledge through legal means without fault by the Receiving Party,

1.4.2. is already public knowledge prior to the Disclosing Party's disclosure of the same to the Receiving Party,

1.4.3. is known to the Receiving Party prior to the Disclosing Party's disclosure of the same pursuant to this Agreement, or

1.4.4. is independently developed by the Receiving Party without reference to or use of the Confidential Information.

DUTIES

With respect to the Disclosing Party's Confidential Information, the Receiving Party agrees that he shall secure and keep such Confidential Information and:

1.5. not disclose it, or allow it to be disclosed in whole or in party to any third party without the consent of Safaricom;

1.6. keep it in a safe and secure place and use reasonable measures to prevent unauthorized access, destruction, corruption or loss;

1.7. not make any copies, summaries or transcripts of it unless this is strictly necessary for the Purpose (all such copies, summaries or transcripts will be deemed to be Confidential information;

1.8. not export it or permit it to be exported in breach of any relevant export regulation;

1.9. notify the Disclosing Party immediately hebecomes aware that any Confidential Information has been disclosed to, or is in the possession of any person or company undertaking any business in competition with the Disclosing Party;

1.10. Notwithstanding the foregoing, the Receiving Party shall be entitled to release Confidential Information to permit it to prosecute or defend any claim under this Agreement or pursuant to an order of a court or government agency; provided, however, in the case of release pursuant to this clause, the Receiving Party shall limit the release to the greatest extent reasonably possible under the circumstances and shall have provided the Disclosing Party with sufficient advance notice to permit the Disclosing Party to seek a protective order or other order protecting its Confidential Information from disclosure.

OWNERSHIP

All Confidential Information, including that which is contained in files, letters, memoranda, reports, records, data, sketches, drawings, notebooks, program listings, or other written, photographic, or other tangible, intangible, or other materials, or which shall come into a Receiving Party's custody or possession, is and at all times shall be the exclusive property of the Disclosing Party, to be used by the Receiving Party only for the purposes expressly contemplated by this Agreement.

NO RIGHTS OR LICENSES GRANTED

The Receiving Party shall not acquire hereunder any right whatsoever to any Confidential Information, including without limitation any right or license of any patent, trademark, copyright, trade secret, moral right or any other right now or later recognized by any law or regulation of any jurisdiction throughout the universe (collectively, "**Intellectual Property Rights**") as a result of or in connection with any disclosure hereunder. Accordingly, nothing in this Agreement is intended or shall be construed as a transfer, grant, license, release or waiver of any Intellectual Property Rights in any Confidential Information.

RETURN OF CONFIDENTIAL INFORMATION

At the request of the Disclosing Party or upon termination of this Agreement, the Receiving Party shall promptly destroy all of its copies of such Confidential Information or return the same to Disclosing Party and make no further use or disclosure of it and in either case shall, within fourteen (14) days of receiving such a request, obtain a certification in writing of his compliance with the terms of this provision. After such destruction or delivery, the Receiving Party shall not retain any copies thereof.

NO OBLIGATION

Nothing in this Agreement shall be deemed to obligate the Disclosing Party to disclose any Confidential Information to the Receiving Party.

REMEDY

The Receiving Party acknowledges the insufficiency of monetary damages as a remedy for any breach of this Agreement by a Receiving Party, and that any such breach could cause the Disclosing Party irreparable harm. Accordingly, the Disclosing Party, as the case may be, in addition to any other remedies available at law, shall be entitled to specific performance and injunctive or other equitable relief as a remedy for any such breach. If litigation arises relating to this Agreement, and a court of competent jurisdiction determines that the Receiving Party, has breached this Agreement, the Receiving Party shall be liable and shall pay to the Disclosing Party the reasonable legal fees incurred by the prevailing Party in connection with such litigation, including any appeals therefrom.

SEVERABILITY

The invalidity or unenforceability of any provision of this Agreement shall not affect the validity or enforceability of any other provision of this Agreement.

NO WAIVER

No delay or omission by the Disclosing Party in exercising any right under this Agreement will operate as a waiver of that or any other right. A waiver or consent given by the Disclosing Party on any occasion is effective only in that instance and will not be construed as a bar to or waiver of any right on any other occasion.

GOVERNING LAW

This Agreement shall be governed by and construed in accordance with the laws of Kenya.

ARBITRATION

11.1 Any dispute arising out of or in connection with this Agreement shall be referred to arbitration by a single arbitrator to be appointed by agreement between the parties or in default of such agreement within fourteen (14) days of the notification of a dispute, upon the application of either party, the arbitrator shall be appointed by the Chairman for the time being of the Kenya Branch of the Chartered Institute of Arbitrators of the United Kingdom.

11.2 Such arbitration shall be conducted in Nairobi in accordance with the Rules of Arbitration of the said Institute and subject to and in accordance with the provisions of the Arbitration Act 1995.

11.3 To the extent permissible by law, the determination of the Arbitrator shall be final conclusive and binding upon the parties.

11.4 Pending final settlement or determination of a dispute, the parties shall continue to perform their subsisting obligations hereunder.

11.5 Nothing in this Agreement shall prevent or delay a party seeking urgent injunctive or interlocutory relief in a court having jurisdiction.

NO RELATIONSHIP CREATED

Nothing in this Agreement shall be construed as establishing or implying any partnership, or agency between the Parties, or authorize the Receiving Party to commit or bind the Disclosing Party in any way whatsoever without obtaining the Disclosing Party's prior written consent.

TERM

The disclosure under this Agreement shall commence on the Effective Date and shall continue for a period of two (2 years unless sooner terminated upon prior written notice of at least one (1) month by one Party to the other. The obligations of confidentiality on the Receiving Party under this Agreement with respect to all Confidential Information shall survive the termination or expiration of this Agreement.

AMENDMENTS IN WRITING

No amendment or modification of any term of this Agreement shall be valid or binding on the Parties unless made in writing and executed on behalf of each Party by a duly authorized representative.

NO WARRANTY

NO WARRANTY

No disclosure of any Confidential Information by the Disclosing Party shall constitute any representation or warranty by the Disclosing Party regarding the accuracy of the same or the non-infringement of any patent, trademark, copyright or any other intellectual property or Confidential right.

NO PUBLICATION

The Receiving Party shall not publicize or advertise in any manner the Confidential information contemplated by the Agreement without the prior written consent of the Disclosing Party, except as may be required by law.

ENTIRE AGREEMENT

This Agreement constitutes the entire agreement between the Parties hereto concerning the subject matter hereof and supersedes any prior or contemporaneous agreements and understandings concerning the subject matter hereof.

COUNTERPARTS

This Agreement and any amendment hereto may be executed in counterparts, each of which when executed and delivered shall be deemed an original and all of which taken together shall constitute one and the same instrument. This Agreement may be delivered by facsimile.

NOTICES

All notices, requests and consents under this Agreement shall be in writing and shall be deemed to have delivered (a) on the date personally delivered, (b) on the date mailed, postage prepaid by certified mail with return receipt requested.

The Parties select as their respective addresses, the addresses set out below for all purposes arising out of or in connection with this Agreement at which addresses only all processes and notices arising out of or in connection with this Agreement may validly be served upon or delivered by the Parties.

SAFARICOM: The Chief Executive Officer
Safaricom Limited
Safaricom House

Waiyaki Way, Westlands
P.O. Box 66827-00800
Nairobi, Kenya.

THE STUDENT: [●]
c/o[●]
[●]

HEADINGS

Headings used in this Agreement are for reference only and shall not affect the interpretation of this Agreement in any way.

IN WITNESS WHEREOF, the Parties hereto have executed this Agreement as of the Effective Date and agree to be legally bound by all terms and conditions contained herein.

SIGNED BY:…………………………………….
Duly authorised for and on behalf of: *(Signature)*
SAFARICOM LIMITED

in the presence of:

SIGNED BY:
Duly authorised for and on behalf of:
……………………………………..
(Name & Title) ………………………………….
(Signature)

In the presence of:

APPENDIX 3: INDEMNITY IN RESPECT OF THE RESEARCH

[ON NOTEPAPER OF UNIVERSITY]

[Insert Date0

Safaricom Limited
Safaricom House
Waiyaki Way
P.O. Box 66827-00100
NAIROBI

Dear Sirs

RE: INDEMNITY IN RESPECT OF THE RESEARCH TO BE UNDERTAKEN BY [●] AT SAFARICOM LIMITED

We refer to the above matter.

We write to confirm that [●] is a PHD student based at the [●]Infulfilment of the requirements for PHD project,[●]will be focusing on the [●]

[●] has by an email dated [●]requested to be allowed to undertake his research at Safaricom Limited. We are aware that in the course of his research he may receive Confidential Information utilized in the course of Safaricom's business operations.

In this regard the [●]hereby agrees to indemnify and hold harmless Safaricom Limited from and against all claims, liabilities, losses, damages, and expenses incurred (including any legal costs or penalties and liabilities awarded or imposed by a court or expenses properly incurred) by [●]pursuant to any breach or non-observance by his obligations or warranties under the Non-Disclosure Agreement which he has executed with Safaricom Limited.

SEALED with the common seal of)
the**[ ]**)
)
)
)
In the presence of)
)
)
………………………………………………..)
)
)
…………………………………………………)

IPCC. (2012). *Renewable Energy Sources and Climate Change Mitigation Special Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

APPENDIX 4: SEKENANI SITE RECORDS

	DATE	GEN HRS	FUEL LEVEL	QTY LTRS	TOP LEVEL
			BEFORE TOP UP	FILLED	AFTER FILLING
1	28/05/2015	17976	700	440	1140
2	14/07/2015	18082	700	700	1400
3	7/1/2015	8201	750	400	1150
4	4/8/2015	18377	350	600	950
5	2/9/2015	18576	350	400	750
6	15/09/2015	18670	300	700	1000
7	25/10/2015	18814	550	940	1530
8	22/11/2015	19220	300	800	1100
9 10	22/12/2015	19511	10	220	230
11	29/12/2015	19567	60	300	360
12	7/1/2016	19634	150	120	270
13	14/01/2016	19701	10	150	160
14	20/01/2016	19755	10	150	160
15	22/01/2016	F	15	250	265
16	27/01/2016	F	20	140	160
17	29/01/2016	F	15	520	535
18	8/2/2016	F	20	350	370
19	19/02/2016	19806	50	650	700
20	29/02/2016	19859	410	300	790
21	29/03/2016	19982	350	100	450
22	14/04/2016	20085	50	300	350

23	13/06/2014	13026	25	740	765
24	26/06/2014	13165	280	500	780
25	9/7/2014	13352	80	700	780
26	16/07/2014	13430	100	750	850
27	27/07/2014	13615	20	450	470
28	4/8/2014	13708	100	450	550
29	13/08/2014	13715	50	100	150
30	15/08/2014	13852	30	100	130
31	17/08/2014	13870	50	600	650
32	19/08/2014	14026	20	100	120
33	30/08/2014	14052	30	100	130
34	18/09/2014	14300	80	150	230
35	22/09/2014	14359	10	1050	1060
36	10/10/2014	14620	80	700	780
37	24/10/2014	14801	20	800	820
38	8/11/2014	15041	60	700	760
39	21/11/2014	15223	80	740	820
40	28/11/2014	15345	20	660	680
41	12/12/2014	15536	15	600	615
42	26/12/2014	15727	30	520	550

APPENDIX 5: SEKENANI SITE PEKINS ENGINE SPECIFICATIONS

Engine Speed (rev/min)	Type of Operation	Typical Generator Output (Net)		Engine Power			
				Gross		Net	
		kVA	kWe	kWm	bhp	kWm	bhp
1500	Prime Power	20.3	16.3	18.7	25.1	18.4	24.6
	Standby (maximum)	22.7	18.2	20.6	27.6	20.3	27.2
1800	Prime Power	23.4	18.7	22.0	29.5	21.6	28.9
	Standby (maximum)	25.3	20.2	24.3	32.6	23.9	32.1
3000	Prime Power	33.8	27.0	31.2	41.8	30.2	40.5
	Standby (maximum)	36.7	29.3	34.4	46.1	33.4	44.8

APPENDIX 6: HOMER SEKENANI SITE RECORDS

	WIND ENERGY	SOLAR PVC	DIESEL GEN	DIESEL GEN	TOTAL ELECTRICAL	AVERAGE
	PRODUCTION	PRODUCTION	PRODUCTION	FUEL	LOAD	WIND SPEED
	KWh	KWh	KWh	LITERS	KWh	m/s
JANUARY	756.25	1794.76	507.01	191.66	1470.25	4.58
FEBRUARY	795.32	1757.54	376.97	142.54	1310.96	4.8
MARCH	860.22	1929.22	488.48	187.5	1524.69	4.76
APRIL	857.11	1720.46	490.36	184.98	1455.68	4.81
MAY	966.92	1709.12	449.74	170.29	1454.7	4.95
JUNE	1048.44	1612.35	472.56	180.01	1451.88	5.16
JULY	1158.16	1649.04	382.64	147.46	1476.11	5.28
AUGUST	1293.78	1741.39	422.27	160.9	1539.32	5.5
SEPTEMBER	1189.34	1813.04	434.78	168.53	1461.73	5.39
OCTOBER	1065.89	1798.18	419.32	161.16	1460.42	5.12
NOVEMBER	833.61	1593.94	465.86	175.34	1428.12	4.76
DECEMBER	721.44	1707.58	519.71	195.34	1488.14	4.48
HILIGHTS	{ I }	{ II }	{ III }	{ IV }	{ V }	
TOTALS	*11546.48*	*20826.62*	*5429.7*	*2065.71*	*17522*	

	WIND ENERGY PRODUCTION KWh	SOLAR PVC PRODUCTION KWh	DIESEL GEN PRODUCTION KWh	DIESEL GEN FUEL LITERS	TOTAL ELECTRICAL LOAD KWh	AVERAGE WIND SPEED m/s
JANUARY	756.25	1794.76	507.01	191.66	1470.25	4.58
FEBRUARY	795.32	1757.54	376.97	142.54	1310.96	4.8
MARCH	860.22	1929.22	488.48	187.5	1524.69	4.76
APRIL	857.11	1720.46	490.36	184.98	1455.68	4.81
MAY	966.92	1709.12	449.74	170.29	1454.7	4.95
JUNE	1048.44	1612.35	427.56	180.01	1451.88	5.16
JULY	1158.16	1649.04	382.64	147.46	1476.11	5.28
AUGUST	1293.78	1741.39	422.27	160.9	1539.32	5.5
SEPTEMBER	1189.34	1813.04	434.78	168.53	1461.73	5.39
OCTOBER	1065.89	1798.18	419.32	161.16	1460.42	5.12
NOVEMBER	833.61	1593.94	465.86	175.34	1428.12	4.76
DECEMBER	721.44	1707.58	519.71	195.34	1488.14	4.48
TOTALS	*11546.48*	*20826.62*	*5384.7*	*2065.71*	*17522*	

APPENDIX 7: HOMER SEKENANI SITE RECORDS WIND SPEEDS VS ENERGY PRODUCTION

	WIND SPEED AVERAGE m/s		WIND SPEED AVERAGE cm/s	WIND ENERGY PRODUCTION KWh
JANUARY	4.58	JANUARY	458	756.25
FEBRUARY	4.8	FEBRUARY	480	795.32
MARCH	4.76	MARCH	476	860.22
APRIL	4.81	APRIL	481	857.11
MAY	4.95	MAY	495	966.92
JUNE	5.16	JUNE	516	1048.44
JULY	5.28	JULY	528	1158.16
AUGUST	5.5	AUGUST	550	1293.78
SEPTEMB	5.39	SEPTEMBER	539	1189.34
OCTOBER	5.12	OCTOBER	512	1065.89
NOVEMBI	4.76	NOVEMBER	476	833.61
DECEMBE	4.48	DECEMBER	448	721.44
TOTALS				**11546.48**

APPENDIX 8: SEKENANI SITE FUEL & GENERATOR HOUR RECORDS

	LITERS	LITERS	LITERS	LITERS	READING	MONTH	LITERS	MONTH
Fuel_Time	Quantity	Quantity	Quantity	Consumed	Gen		CONSUMEI	GEN.
	Before	Fueled	After		Hours			Hours
4/14/2016 16:13	50	300	350	400	20085	16-Apr	400	103
3/29/2016 14:27	350	100	450	440	19982	16-Mar	440	123
2/29/2016 15:26	490	300	790	210	19859	16-Feb	1045	292
2/14/2016 15:32	50	650	700	320	19806			
2/8/2016 4:08	20	350	370	515	0			
1/29/2016 16:20	15	520	535	145	0	16-Jan	1155	
1/27/2016 20:20	20	140	160	250	0			
1/22/2016 18:54	20	250	270	140	0			
1/20/2016 9:48	10	150	160	150	19755			
1/14/2016 14:55	10	150	160	260	19701			
1/7/2016 9:31	150	120	270	210	19634			
12/29/2015 17:31	60	300	360	1040	19567	15-Dec	1040	347
11/22/2015 9:22	300	800	1100	1230	19220	15-Nov	1230	406
10/5/2015 19:25	550	980	1530	450	18814	15-Oct	450	144
9/15/2015 13:14	300	700	1000	450	18670	15-Sep	1050	293
9/2/2015 15:06	350	400	750	600	18576			
8/4/2015 11:44	350	600	950	800	18377	15-Aug	800	176
7/1/2015 16:04	750	400	1150	650	18201	15-Jul	650	119
6/14/2015 14:51	700	700	1400	440	18082	15-Jun	440	106
5/28/2015 10:53	700	440	1140	500	17976	15-May	1150	355
5/10/2015 12:47	600	600	1200	650	17820			
4/25/2015 12:29	550	700	1250	400	17621	15-Apr	1550	492
4/17/2015 14:03	350	600	950	1150	17498			
3/25/2015 16:12	800	700	1500	400	17129	15-Mar	1250	349
3/15/2015 14:21	700	500	1200	850	17028			
2/26/2015 20:12	350	1200	1550	415	16780	15-Feb	2015	561
2/20/2015 12:07	15	750	765	95	16678			
2/17/2015 15:04	10	100	110	750	16636.1			
2/5/2015 15:29	10	750	760	755	16449			
1/22/2015 14:09	15	750	765	475	16219	15-Jan	995	492
1/11/2015 17:50	30	460	490	520	16045			
12/22/2014 20:34	30	520	550	585	15727	14-Dec	1250	406
12/12/2014 20:03	15	600	615	665	15536			
11/28/2014 19:17	20	660	680	300	15321	14-Nov	220	98
11/21/2014 14:42	80	240	320	-80	15223			

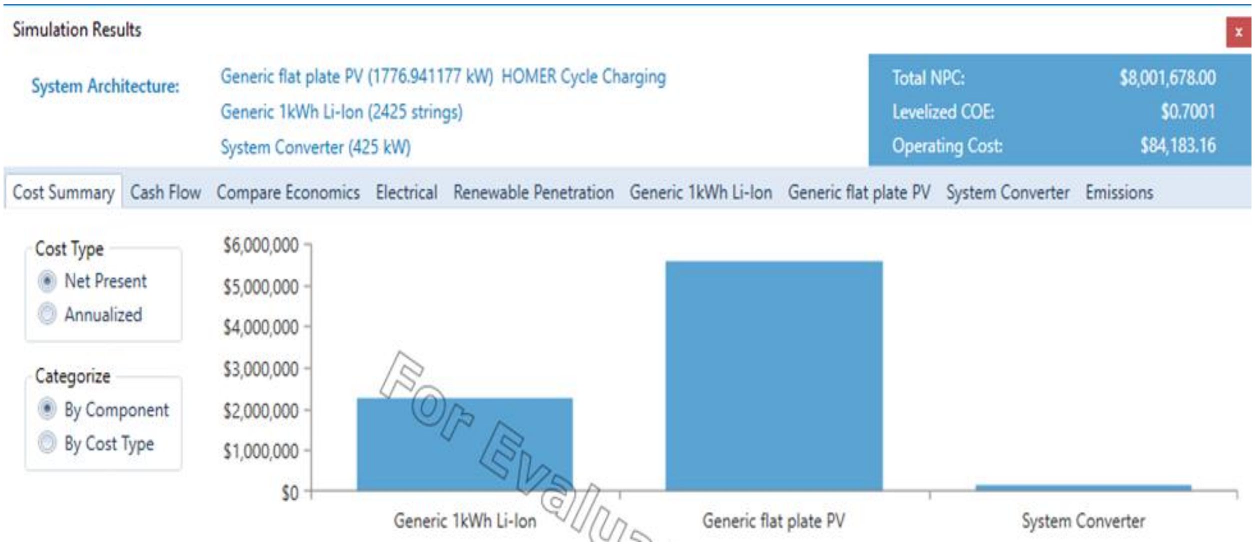
APPENDIX 9: SEKENANI SITE AVERAGE WIND SPEED, WIND ENERGY AND SOLAR ISOLATION (NAROK)

	Wind Speed	Average Wind Energy	Solar Isolation (NAROK)
	cm/s	KWh	KWh/m2/day X 0.01
JANUARY	458	756.25	613
FEBRUARY	480	795.32	663
MARCH	476	860.22	635
APRIL	481	857.11	569
MAY	495	966.92	554
JUNE	516	1048.44	525
JULY	528	1158.16	509
AUGUST	550	1293.78	541
SEPTEMBER	539	1189.34	611
OCTOBER	512	1065.89	563
NOVEMBER	476	833.61	507
DECEMBER	448	721.44	566
		11546.48	

Appendix 10 Simulated NPC values of Hybridized Solar PV and Wind only.

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic 1kWh Li-Ion	$1,455,000.00	$617,318.42	$313,492.26	$0.00	($116,185.56)	$2,269,625.12
Generic flat plate PV	$5,330,823.53	$0.00	$229,714.39	$0.00	$0.00	$5,560,537.92
System Converter	$127,575.41	$54,126.91	$0.00	$0.00	($10,187.23)	$171,515.09
System	$6,913,398.94	$671,445.33	$543,206.65	$0.00	($126,372.79)	$8,001,678.13

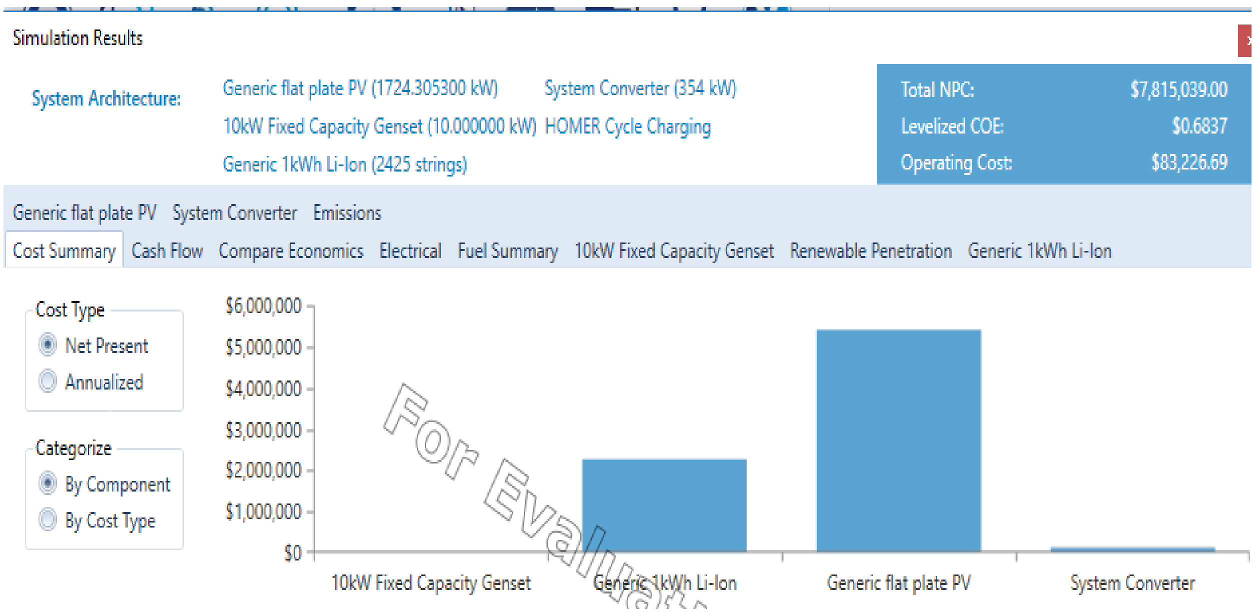
Appendix 11 Graph of the Simulated NPC of the Solar PV hybrid with the Wind turbine



Appendix 12 Simulated NPC of the Hybridized Solar PV , diesel Generator and Wind turbine

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
10kW Fixed Capacity Genset	$5,000.00	$0.00	$271.47	$2,585.35	($1,058.05)	$6,798.77
Generic 1kWh Li-Ion	$1,455,000.00	$617,318.42	$313,492.26	$0.00	($116,185.56)	$2,269,625.12
Generic flat plate PV	$5,172,915.90	$0.00	$222,909.86	$0.00	$0.00	$5,395,825.76
System Converter	$106,208.93	$45,061.67	$0.00	$0.00	($8,481.06)	$142,789.54
System	$6,739,124.83	$662,380.09	$536,673.59	$2,585.35	($125,724.67)	$7,815,039.19

Appendix 13 Graph of the Simulated NPC of Hybridized Solar PV, Diesel Generator and Wind turbine



	HOMER	ACTUAL
	Liters	Liters
JANUARY	191.66	995
FEBRUARY	142.54	2015
MARCH	187.5	1250
APRIL	184.98	1550
MAY	170.29	1150
JUNE	180.01	440
JULY	147.46	650
AUGUST	160.9	800
SEPTEMBER	168.53	1050
OCTOBER	161.16	450
NOVEMBER	175.34	1230
DECEMBER	195.34	1040
	2065.71	12620

DATE	GEN HRS	HOURS	FUEL LEVEL	QTY LTRS	TOP LEVEL
			BEFORE TOP UP	FILLED	AFTER FILLING
28/05/2015	17976	401	700	440	1140
14/07/2015	18082		700	700	1400
7/1/2015	8201		750	400	1150
4/8/2015	18377	199	350	600	950
2/9/2015	18576	94	350	400	750
15/09/2015	18670	144	300	700	1000
25/10/2015	18814	406	550	940	1530
22/11/2015	19220	291	300	800	1100
22/12/2015	19511	56	10	220	230
29/12/2015	19567	67	60	300	360
7/1/2016	19634	67	150	120	270
14/01/2016	19701	54	10	150	160
	6 MONTHS		10	150	160
22/01/2016	F		15	250	265
27/01/2016	F		20	140	160
29/01/2016	F	105	15	520	535
8/2/2016	F		20	350	370
19/02/2016	19806	53	50	650	700
29/02/2016	19859	123	410	300	790
29/03/2016	19982	2060	350	100	450
DATE	GEN HRS	HOURS	50	300	350
13/06/2014	13026	139	25	740	765
26/06/2014	13165	187	280	500	780
9/7/2014	13352	78	80	700	780
16/07/2014	13430	185	100	750	850
27/07/2014	13615	93	20	450	470
4/8/2014	13708	7	100	450	550
13/08/2014	13715	137	50	100	150
15/08/2014	13852	18	30	100	130
17/08/2014	13870	156	50	600	650
19/08/2014	14026	26	20	100	120
30/08/2014	14052	52	30	100	130
18/09/2014	14300	59	80	150	230
22/09/2014	14359	261	10	1050	1060
10/10/2014	14620	181	80	700	780
24/10/2014	14801	240	20	800	820
8/11/2014	15041	182	60	700	760
21/11/2014	15223	122	80	740	820
28/11/2014	15345	191	20	660	680
12/12/2014	15536	191	15	600	615
26/12/2014	15727		30	520	550
TOTAL	***12 MONTHS***	***4565***			

	LITERS	LITERS	LITERS	LITERS	READING		MONTH	LITERS	MONTH		
Fuel_Time	Quantity_	Quantity_	QUANTITY	CONSUME	Gen_Hours			CONSUME	GEN. HOURS		
4/14/2016 16:13	50	300	350	400	20085		16-Apr	400	103		3.883
3/29/2016 14:27	350	100	450	440	19982		16-Mar	440	123		3.577
2/29/2016 15:26	490	300	790	210	19859		16-Feb	1045	292		3.579
2/14/2016 15:32	50	650	700	320	19806						
2/8/2016 4:08	20	350	370	515	0						
1/29/2016 16:20	15	520	535	145	0		16-Jan	1155			
1/27/2016 20:20	20	140	160	250	0						
1/22/2016 18:54	20	250	270	140	0						
1/20/2016 9:48	10	150	160	150	19755						
1/14/2016 14:55	10	150	160	260	19701						
1/7/2016 9:31	150	120	270	210	19634						
12/29/2015 17:31	60	300	360	1040	19567		15-Dec	1040	347		2.997
11/22/2015 9:22	300	800	1100	1230	19220		15-Nov	1230	406		3.03
10/5/2015 19:25	550	980	1530	450	18814		15-Oct	450	144		3.125
9/15/2015 13:14	300	700	1000	450	18670		15-Sep	1050	293		3.584
9/2/2015 15:06	350	400	750	600	18576						
8/4/2015 11:44	350	600	950	800	18377		15-Aug	800	176		4.545
7/1/2015 16:04	750	400	1150	650	18201		15-Jul	650	119		5.462
6/14/2015 14:51	700	700	1400	440	18082		LL	440	106		4.151
5/28/2015 10:53	700	440	1140	500	17976		15-May	1150	355		3.239
5/10/2015 12:47	600	600	1200	650	17820						
4/25/2015 12:29	550	700	1250	400	17621		15-Apr	1550	492		3.15
4/17/2015 14:03	350	600	950	1150	17498						
3/25/2015 16:12	800	700	1500	400	17129		15-Mar	1250	349		3.582
3/15/2015 14:21	700	500	1200	850	17028						
2/26/2015 20:12	350	1200	1550	415	16780		15-Feb	2015	561		3.592
2/20/2015 12:07	15	750	765	95	16678						
2/17/2015 15:04	10	100	110	750	16636.1						
2/5/2015 15:29	10	750	760	755	16449						
1/22/2015 14:09	15	750	765	475	16219		15-Jan	995	492		2.022
1/11/2015 17:50	30	460	490	520	16045						
12/22/2014 20:34	30	520	550	585	15727		14-Dec	1250	406		3.079
12/12/2014 20:03	15	600	615	665	15536						
11/28/2014 19:17	20	660	680	300	15321		14-Nov	220	98		2.245
11/21/2014 14:42	80	240	320	-80	15223						