DESIGN OF A SOLAR PV ENERGY SYSTEM FOR WAJIR TOWN, WAJIR

COUNTY, KENYA

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MASTER OF SCIENCE

(Energy Technology)

JOMO KENYATTA UNIVERSITY

OF AGRICULTURE AND TECHNOLOGY

2018

Design of a Solar PV Energy System for Wajir Town, Wajir County, Kenya

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A Thesis Submitted in Partial Fulfillment for the Degree of Master of Science in Energy Technology in the Jomo Kenyatta University of Agriculture and Technology

2018

DECLARATION

This Thesis is my original work and has not been submitted for a degree in any other University.

Signature ………………………………………….. Date ………………………

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

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DEDICATION

I dedicate this thesis to my sister Timira Diyad Elmi and her husband Mohamed Ali Farah who never stopped imploring for my success. I also dedicate to my late parents' mom Gurai Jehow and Sargent Diyad Elmi who passed on whilst I was in early age. Lastly to my daughter Ridwan Mohamed Ali

ACKNOWLEDGEMENT

First of all, I give my sincere praise and thanks to Almighty ALLAH; He is always my only support in every corner of my life. I thank Him for guiding and helping me to be unswerving throughout. My deepest appreciation also goes to Jomo Kenyatta University of Agriculture and Technology for providing the opportunity to attain this masters' degree.

I would like to express my profound and sincere gratitude to my supervisors Prof. Robert Kinyua and Prof. Joseph Kamau for their boundless support, endurance, inspiration, enthusiasm, and immense knowledge. Their guidance helped me in all the time of research and writing of this thesis. My honest thanks to all of my friends, relatives and families for their support and encouragement during my study to accomplish my goals.

Lastly, I wish to express my sincere thanks to all those who have in one way or another helped me in making this thesis successful.

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LIST OF ABBREVIATION

CSP	Concentrated Solar Power
DSPV	Dye Sensitized Photovoltaic
ERC	Energy Regulatory Commission
FIT	Feed-in-Tariff
FPC	Flat panel collectors
GCEP	Global Climate and Energy Project
GWh	Gigawatt hours
Inv	Investments
IEA	International Energy Agency
JKUAT	Jomo Kenyatta University of Agriculture and Technology
Kwp	kilowatt peak
kWh/m^2/day	kilowatt hour per square metre per day
Ksh	Kenyan shilling
LFR	Linear Frensel Collector
MJ/m^2/day	Mega joule per square metre per day
NCPD	National Council for Population and Development

PDR	Parabolic Dish Reflector
PTC	Parabolic Trough Collector
PV	Photovoltaic
RTM	Radioactive Transfer Model
SPH	Solar Peak Hours
STA	Solar Thermoelectricity System
STS	Solar Thermoelectricity System
TW	Terawatt
US$	United States Dollar
VAT	Value Added Tax

ABSTRACT

Solar PV systems are suitable for areas where grid connections are unavailable. Northeastern Kenya, being an off grid area, requires an alternative energy source to close the gap of electricity shortages. This Study presents the development of an effective approach of designing, assessing, analyzing and determining economic viability of solar energy availability in Wajir town. Situated in the north-eastern part of Kenya with population of 0.7 million, the county receives about 300 sunny days in a year. The unique weather profile favors the adoption of the solar energy technology. Solar Radiation was recorded for three months (October, November and December 2016) and also from the meteorological headquarters from the year 2000 to 2010. Results revealed that Wajir has an average daily insolation of 6.6 kWh/m^2. Energy demand survey of 20 households, 20 shops and the main hospital were conducted and later on design using Sunny Web design software was used to model by approximating 300 households, 20 shops and the main referral hospital. Sizing for PV array, inverters and modules were done to obtain 122.25 kWp system for households, 25 kWp system for shops and 239 kWp system for the hospital. Calculated costs for the households, shops and the hospital are US$ 164714, US$2315 and US$282873.7 respectively with payback period of the whole design being 6-7 years.

CHAPTER ONE

INTRODUCTION

1.1 Background

It has been predictable that 2.4 billion people heavily rely on charcoal, wood, agricultural residues and dung for cooking and space heating. The International Energy Agency (IEA), (IEA, 2015), reported that these figures will persist unchanged unless new strategies are embraced to expand access to modern energy services. “Most people in developing countries, especially in rural areas, have to rely deeply on traditional fuels for cooking, which have severe negative impacts to human health and the environment. More than 1.6 million women and children die every year because of respiratory diseases caused by indoor air pollution from cooking fuels. In developing countries, poor people spend a higher share of their income on energy services than people in developed parts of the world. Costs per energy unit are also higher (IEA, 2015). Candles and batteries prove to be the most expensive forms of energy per unit. Four out of five people without access to electricity live in rural areas. Several developing countries like Kenya have abundant renewable energy resources including solar energy, but are not effectively utilized. Modern energy services are crucial to human well-being and to a country’s economic development; and yet globally 1.2 billion people are without access to electricity and more than 2.7 billion people are without clean cooking facilities (IEA, 2015). More than 95% of these people are either in sub-Saharan African or developing Asia, and around 80% are in rural areas (IEA, 2015). Renewable Energy resources play an important role in the development of human society. Since the industrial revolution, energy has been a driving force for the modern civilization development. In Kenya the use of renewable energy is scaling up to reduce energy demand and minimize power deficiency but as the population increase so does the energy demand.

Contingent on the conversion efficiency of solar modules, ten to fourteen percent (10-14%) of this energy can be converted to electric power. However, there are regional and seasonal differences in the solar resources of the country. Seasonally, for instance, Wajir County is ever hot throughout the year which is approximately 300 days of sun as compared to the other regions in the country which has variable seasons. The government of Kenya greatly focuses on clean energy since clean energy has no environmental degradation. It is estimated that photovoltaic (PV) systems will experience an enormous increase in the decades to come. However, a successful integration of solar energy technologies into the existing energy structure depends also on a detailed knowledge of the solar resource (Omwando *et al.,* 2013).

Wajir being located in the tropics where the intense heating exist on earth can have a great opportunity as far as resource utilization is concerned. Comparing the available energies (electricity, charcoal, firewood and kerosene) and the use of solar energy, there are 88574 households in Wajir. 3039 households use electricity, 14948 households use kerosene for lighting, and 155 households use fuel woods or firewood, 26296 households' uses solar directly and indirectly, (Knoema, 2017).

This is evident that Wajir Town heavily relay on fossil fuel and therefore the need to utilize the available solar energy resource so as to cut constant depending on fossil fuel.

1.2 Energy Demand in Kenya

In Kenya there are three main sources of energy namely woody biomass (68%), petroleum fuels (22%) and electricity (9%). These competing energy sources have impacted negatively on the environment (Wasike, 2015). It is anticipated that 80% of the population depend on biomass, Kenya's overreliance on biomass as a source of energy is proliferated by poor rural electrification. Currently, Kenya imports 100% of its petroleum needs. Nevertheless, economically utilizable oil deposits were discovered in north-western Kenya in 2012; Africa Oil and its partner Tullow Oil, who made the discovery are projecting to start small-scale production of crude oil, transported by road and rail to the Kenyan port of Mombasa, in 2017. However, low oil prices and Uganda's recent decision to withdraw support from Kenya, and partner with Tanzania instead, in the construction of a port and transport corridor known as LAPSSET (the Lamu Port and South Sudan Ethiopia Transport) may impede Kenya's establishment as a major oil exporter (Miles *et al.*, 2017).

Kenya's electricity is mainly from geothermal (47% of consumption), hydropower (39%), thermal (13%) and wind (0.4%). Kenya's present installed electricity capacity is estimated at 2.4 GW, 1.5 GW of which is grid-connected and 500 MW of which has come online since mid- 2014. Since hydropower accounts for a large percentage of this capacity and is reliant on unpredictable weather conditions, the frequency of power outages is high at 33% (compared to an average of 1% for Mexico, China and South Africa). The cost of energy in Kenya is also high at US$0.150 per kWh, almost four times the cost of energy in South Africa (US$0.040) (Miles *et al.,* 2017).

Electricity consumption reached 6,581 GWh in 2012/13, increasing by 73% from 2007/8. Large and medium companies are the largest consumers, consuming about twice as much power as domestic consumers. It should be noted that the current tariff pattern favours large firms, compared to small firms and households. This is evident from revenue collection that large and medium companies yielded 48% less revenue than households and 79% less revenue than small commercial consumers' respectively (Miles *et al.,* 2017).

Whilst electricity generation in Kenya is still almost entirely operated by state-owned companies or companies in which the government is the principal shareholder, the participation of independent power producers (IPPs) is growing. There are approximately ten IPPs in operation and they account for about 24% of the country's installed capacity, up from 11% in 2008. One of the key components of the Kenyan government's energy strategy is a strong emphasis on the participation of private investors in the development of the electricity sector, so the current trend is likely to continue, at least in the medium term. However, there are concerns about the low efficiency of power production by IPPs (Miles *et al.,* 2017).

The cost of the current plan of electrification is estimated at US$1.3billion over the next 3−4 years, highlighting the need for private investors in the sector. However, the number of IPPs interested in investing is low and those that indicate interest demand high generation tariffs, government guarantees and letters of credit covering several months of payment for both capital and energy charges. Kenya also imports electricity from Uganda (accounting for 95% of power imports) and Ethiopia, but has cut its power imports by more than half following the injection of geothermal power to the national grid. Data from the Energy Regulatory Commission indicates that Kenya imported 27.97 million kWh in the first half of 2015, following the injection of 280 MW of geothermal power to the national grid, down from 57.91 million kWh in the same period in 2014 (Miles *et al.*, 2017).

Kenya has great potential in the geothermal sphere, accounting for 7 of the 15 Gigawatt of potential geothermal energy in Africa. In fact, it is the world's 8^{th} largest producer of geothermal energy. Additionally, high subsurface temperatures make it cheaper to produce geothermal energy here. Kenya is home to Africa's largest wind power project (the 310MW Lake Turkana Wind Farm) as well as a further 900MW in development or online (Miles *et al.*, 2017). Kenya receives daily insolation of 4-6 kWh/m^2 (Omwando *et al.*, 2013). Solar utilization is mainly for photovoltaic (PV) systems, drying and water heating. The solar PV systems are used mainly for telecommunication, cathodic protection of pipelines, lighting and water pumping. Some of the barriers affecting the exploitation of solar energy resource include high initial capital costs, low awareness of the potential opportunities and economic benefits offered by solar technologies, and a lack of adherence to system standards by suppliers (Omwando *et al.,* 2013).

The Government has zero-rated the import duty and removed Value Added Tax (VAT) on renewable energy equipment and accessories. The Energy Regulatory Commission, (ERC, 2015), has prepared and gazette the Energy (Solar Water Heating) Regulations 2012 and The Energy (Solar Photovoltaic) Regulations 2012 to provide the much needed policy framework. Vibrant solar energy market has developed in Kenya over the years for providing electricity to homes and institutions remote from the national grid and for medium temperature water heaters for domestic and commercial usage (ERC, 2015). A preliminary survey done in 2005 established that the annual market demand for Photo Voltaic (PV) panels was 500 kilowatt peak (kWp) and this was projected to grow at 15% annually (ERC, 2015).

1.3 Statement of the problem

Wajir as a county experiences massive power failure. This is due to insufficient power from Diesel power plant manned by Kenya Power Lighting and Company. Constant use of biomass sources such as charcoal and firewood results serious Environmental degradation. Climate change and energy security also pose threat, therefore the need for clean and reliable energy. Consequently, there is a need to promote ecological, alternative, new and renewable sources of energy in the rural areas of the country. Solar energy is reliable and more environmentally friendly. This resource is therefore one of the better energy alternatives for Wajir county for socio-economic development.

1.4 Justification

Solar energy can be used for lighting, drying and generating electricity. Kenya's topographical location spanning the equator gives it unique opportunity for a lively solar energy market. Situated in the north-eastern part of Kenya with population of 0.7 million, the county receives about 300 sunny days in a year. Mostly, the daytime is extremely long in the summer time from 7:00 am to 6:00 pm.

1.5 Research objectives

1.5.1 Main objective

The main objective of this study was to empirically design solar energy for Wajir Town, Wajir County.

1.5.2 Specific objectives

The specific objectives of the study were:

1. To assess the solar energy potential in Wajir town.
2. To determine the energy demand for households, shops and hospital within Wajir town.
3. To determine economic viability of solar energy in Wajir town using the

Sunny Design Software.

CHAPTER TWO

LITERATURE REVIEW

2.1 Previous work

There have been several research and development studies conducted to examine the performance and feasibility of solar energy systems. However, very few broad studies have been performed on the performance and assessment of solar energy system in rural areas to offset huge dependence on fossil fuel. Wajir County is mainly distinguished by the life style of the people and deeply use of fossil fuel since independence. This literature review addresses up-to date research works on solar energy assessment, evaluation, analysis and performance to leverage continuous use of non-renewable energy.

Radiation and temporal characteristics of global solar radiation have been measured in Nakuru County to examine the potential solar energy. Nakuru is a reasonable to high solar energy potential region, with an average daily insolation of 6.9 kWh/m^2. It was also shown that the energy reaching the surface in this area is season dependent with December-February season receiving the highest amount of 678 kWh/m^2 and September-November season receiving the least amount of 602.6 kWh/m^2 (Omwando *et al.,* 2013). The researchers did not show the demand of solar energy as compared to other sources of energy since they only focused on radiation penetration.

Wasike, (2015) assessed solar radiation in Thika and Nairobi area to provide information on the solar energy source of the two regions using Gunn-Bellani Pyranometer to collect data for analysis. Several studies have been conducted within series of span to show the potential of solar in different part of Kenya. Okoola *et al.,* (2008) observed that insolation reaches its peak during the afternoon session. Marigi, (1999) analyzed that annual insolation of Kenya. Both researchers conducted the assessment alone but never showed the level of the need in terms of future energy for the purpose of electricity generation.

Okonkwo *et al.,* (2014) observed that temperature data could be used to estimate, (to a very reasonable accuracy), the total solar radiation incident on a location. They used maximum and minimum temperature data measured in Minna (09.65°N, 06.47°E), Niger state, for a period of thirteen years (2000 – 2012), to establish Angstrom-type regression equations (models) for estimating the global solar radiation received on a horizontal surface in Minna. The results of the correlation were also tested for error using statistical test methods of the mean bias error (MBE), root mean square error, (RMSE) and mean percentage error (MPE) to assess the performance of the models.

Regmi, (2012) investigated solar energy potential in Kathmandu valley, Nepal. The investigation showed that Pre-monsoon and post monsoon seasons have higher mean monthly sunshine duration (about 8 hours/day) than summer (about 5 hours/day) and winter (about 7 hours/day) seasons over Kathmandu

Kosmopoulos *et al.*, (2017) assessed solar energy potential in Greece using satellite-and ground- based observations in conjunction with radioactive transfer model (RTM) simulations. Pyranometer of the Hellenic Network for Solar Energy and the National Observatory of Athens provide accurate insolation measurements. The total energy potential for each ground station is found to range from 1.5 to 1.9 MWh/m^2 with cloudiness causing increments in the forecast error of the order of 10%. They also present a model for generating instantaneous and accurate gridded surface solar radiation spectra.

According to Global Climate and Energy Project, (GCEP, 2006) Solar radiation represents the largest energy flow entering the terrestrial ecosystem. After reflection and absorption in the atmosphere, some 100,000 TW hit the surface of Earth and undergo conversion to all forms of energy used by humans, with the exception of nuclear, geothermal, and tidal energy. This resource is enormous and corresponds to almost 6,000 fold the current global consumption of primary energy (13.7 TW). Thus, solar energy has the potential of becoming a major component of a sustainable energy portfolio with constrained greenhouse gas emissions.

Two types of PV technology are currently available in the market: crystalline silicon-based PV cells and thin film technologies made out of a range of different semi-conductor materials, including amorphous silicon, cadmium-telluride. Solar thermal technology uses solar heat, which can be used directly for either thermal or heating application or electricity generation. Accordingly, it can be divided into two categories namely; solar thermal nonelectric and solar thermal electric. The former includes applications as agricultural drying, solar water heaters, solar air heaters, solar cooling systems and solar cookers (Kumar *et al., 2014*); the latter refers to use of solar heat to produce steam for electricity generation, also known as concentrated solar power (CSP).

Solar PV cells were invented at Bell Labs in the United States in 1954, and they have been used in space satellites for electricity generation since the late 1950s (Tilmasha *et al.,* 2012). The years proximately following the oil-shock in the seventies saw much interest in the development and commercialization of solar energy technologies. However, this emerging solar energy industry of the 1970s and early 80s collapsed due to the sharp decline in oil prices and a lack of sustained policy support (Tilmasha *et al.,* 2012).

As it has been for the past decades, electricity is expected to be the fastest growing form of energy for use. For the next twenty-five years, the yearly rise in the net electricity generation is estimated to be 2.3%. It is predictable that world energy consumption will increase by about 40% between 2006 and 2030. The growth in the electricity generation is mainly the developing countries where the standards of living rises, infrastructures and population is relatively high (IEA, 2013).

Solar energy markets have recovered momentum since early 2000, exhibiting phenomenal growth recently. The total installed capacity of solar based electricity generation capacity has increased to more than 40 GW by the end of 2010 from almost negligible capacity in the early nineties (Togrul, 2009).

Solar power can match the grid service partly because rural households do not consume much electricity, at least for the first few years. Household electricity usage for those just connected to the grid is often limited to a few lamps (3–6), a radio, and a television, or 30–60 kWh per month. These services can also easily be delivered by solar systems. Household demand remains low for at least a couple of years, after which households will start to add higher power consuming appliances, such as rice cookers, tea kettles, or refrigerators if the grid capacity allows (Robert van der Plas, 1994).

Solar energy has experienced an impressive technological shift. While early solar technologies consisted of small-scale photovoltaic (PV) cells, recent technologies are represented by solar concentrated power (CSP) and also by large-scale PV systems that feed into electricity grids. The costs of solar energy technologies have dropped considerably over the last thirty years. For example, the cost of high power band solar modules has decreased from about US dollar 27,000 per kW in 1982 to about US dollar 4,000 per kW in 2006; the installed cost of a PV system declined from US dollar 16,000 per kW in 1992 to around US dollar 6,000 per kW in 2008 (Saleh, 2000). The rapid growth of the solar energy market can be attributed to a number of helpful policy instruments, the increased volatility of fossil fuel prices and the environmental externalities of fossil fuels, particularly greenhouse gas (GHG) emissions. Theoretically, solar energy has resource potential that far exceeds the entire global energy demand

(Kumar *et al.*, 2014).

The previous studies majorly concentrated on the assessment of solar radiation patterns and the issue of energy estimation, energy demand and consumption was not investigated whereas our study focuses on the energy demand determination, cost benefit analysis and assessment of solar energy in Wajir. The study uses unique techniques to size for the PV systems

2.2 Theoretical Principles

2.2.1 Solar Energy

Solar energy is radiant light and heat from the sun harnessed using a range of ever-evolving technologies such as solar heating, solar photovoltaic, solar thermal electricity, solar architecture and artificial photosynthesis. Solar power has the amazing ability to give us an abundance of energy just by hitting the earth's surface. The spectrum of solar light at the Earth's surface is mostly spread across the visible and near-infrared ranges with a small part in the near-ultraviolet (Wasike, *2015*).

2.2.2 The sun

The sun is a sphere of extremely hot gaseous matter with a length of 1.39×10^{9} m and is on the average, 1.5×10^{11} m from the earth. As seen from the earth, the sun rotates on its axis about once every four weeks. Nevertheless, it does not rotate as a solid body; the equator takes about twenty-seven days and the Polar Regions take about thirty days for each rotation. The sun has an effective blackbody temperature of 5777 K. The temperature in the central inner regions is variously projected at 8×10^6 to 40×10^6 K and the density is estimated to be about 100 times that of water. The sun is, in effect, a continuous fusion reactor with its component gases as the ‘‘containing vessel’’ retained by gravitational forces. Several fusion reactions have been suggested to supply the energy radiated by the sun. The one considered the most important is a process in which hydrogen (four protons) combines to form helium (one helium nucleus); the mass of the helium nucleus is less than that of the four protons, mass having been lost in the reaction and converted to energy (John, 2013).

2.2.3 Solar Radiation

The sun is the basis of most energy on the earth and is a primary factor in determining the thermal environment of a locality. The earth is nearly spherical with a diameter of about 12.7×10^3 km. It makes one rotation about its axis every 24 hours and completes a revolution about the sun in a period of approximately 365 days. (John, 2013). The earth revolves around the sun in a nearly round path, with the sun located slightly off center of the circle. The earth's mean distance to the sun is about 1.5×10^8 km. Around January 1, the earth is closest to the sun while on around July 1 it is most remote, about 3.3% farther away. Since the intensity of solar radiation incident upon the top of the atmosphere varies contrariwise with the square of the earth-sun distance, the earth receives about seven per cent more radiation in January than in July. (John, 2013). The earth's axis of rotation is tilted 23.5 degrees with respect to its orbit about the sun. The earth's tilted position is of profound significance. Together with the earth's daily rotation and yearly revolution, it accounts for the distribution of solar radiation over the earth's surface, the changing length of hours of daylight and darkness, and the changing of the seasons. The solar radiation is generally estimated using sunshine hour data, but even sunshine hour data is not available for many stations. As such the computation of solar radiation can be obtained from air temperature data, by using other meteorological data such as transmission coefficient, gas absorption, absorption by water vapors, absorption and scattering by aerosol and clouds. A number of models had been developed in this regard. For this study we have discussed various models based on sunshine hour data only. Solar photovoltaic systems utilize the photoelectric effect present in semiconductor materials to turn solar energy directly into electricity. While the intensity of total solar radiation received at the top of the atmosphere at the sub solar point is 1367 Wm^{-2}, mean solar radiant intensity incident upon the top of earth’s Atmosphere is a smaller value, but is totally predictable. For this averaged total, the spherical shape of the earth requires that the solar constant be calculated across a circle onto which the solar radiation intercepted by the earth is projected at a given time. When speaking of photovoltaic, there are a number of terminologies that are used to describe certain aspects of a system. First, the electricity is actually generated in what is called a solar cell. The solar constant is the generally accepted value for the flux density of shortwave radiant energy of 1367 Wm^{2} (John, 2013) intercepted on a plane perpendicular to the sun’s rays at the “top” of the atmosphere at mean earth sun distance.

Beam Radiation: is the solar radiation received from the sun without having been scattered by the atmosphere (beam radiation is often referred to as direct solar radiation; to avoid confusion between subscripts for direct and diffuse, we use the term beam radiation, subscript “b”) (John, 2013).

Diffuse Radiation: is the solar radiation received from the sun after its direction has been changed by scattering by the atmosphere (diffuse radiation is referred to, in some meteorological literature, as sky radiation or solar sky radiation; the definition used here will distinguish the diffuse solar radiation from infrared radiation emitted by the atmosphere (John, 2013).

2.2.4 Solar Radiation Measurement

Investigational fortitude of the energy transferred to a surface by solar radiation requires instruments that will measure the heating effect of direct solar radiation and diffuse solar radiation. There are two general classes of solar radiation measuring devices. The instrument D – 13 (pyrheliometer) used to measure direct normal or beam radiation. The other instrument, called a Pyranometer, is able to measure total radiation within its semicircular field of view. A Pyranometer can also be used to measure diffuse radiation alone by shading the sensing element from the sun’s direct rays. The pyrheliometer consists of a long collimating tube with a detector at the far end. The aperture angle of the instrument is 5.7°, so the detector receives radiation from the sun and from an area of the sky two orders of magnitude larger than the sun. The detector consists of a multi-junction thermopile with a blackened surface. Temperature compensation is provided to minimize sensitivity to variations in the ambient temperature. The temperature of the blackened junction of the thermopile is a measure of the solar flux striking it. (John, 2013). The output measured is a dc voltage, typically in the millivolt range, and the manufacturer provides a calibration constant to convert dc voltage to solar flux.

Figure 2.1: Huksflux Pyranometer

Figure 2.1 shows a Pyranometer manufactured by Huksflux. It uses a thermopile detector, two concentric hemispherical optically ground covers to ensure a proper cosine effect and temperature compensation. This type of Pyranometer measures the total solar flux coming from the hemisphere above the detector (the detector is the black disk in the center of the Pyranometer). The units are usually mounted horizontally so they measure the total solar flux striking the horizontal. However, they can be mounted in any orientation. In our experiment involving solar collectors, a Pyranometer is mounted with the detector in the plane of the collectors, thus measuring the total solar flux striking the collector surface (John, 2013).

2.3 Technologies used to convert solar energy

There are several kinds of solar techniques that are currently available. However, each of them is based on quite different concepts and science and each has its unique advantages. Analysis and comparison between different technologies will help to adopt the most efficient and beneficial technology given a specific set of conditions of solar energy (Saleh, 2000). These range from solar collectors on house roofs for space and water heating to solar power plants, with large arrays of mirrors concentrating solar energy to heat water and drive turbines to produce electricity. The type of solar energy conversion system installed in an area depends on the prevailing climate. Generally speaking, non-concentrated photovoltaic (PV) solar panels and concentrated solar power (CSP) are the two most mature technologies, they have been commercialized and expected to experience rapid growth in the future, and thus emphasis will be on these two technologies. Solar thermoelectricity systems (STS), dye sensitized solar cell (DSPV) and concentrated photovoltaic systems are emerging technologies and under intensive study (Togrul, 2009). Eventually, they may claim a significant share of the solar energy market if they achieve the necessary technical breakthroughs to make them sufficiently competitive to be commercialized.

2.3.1 Photovoltaic (PV) Solar Panels

Photovoltaic (PV) is a method of generating electrical power by converting solar radiation into electricity. It employs solar panels composed of a number of solar cells containing a photovoltaic material. Materials presently used for photovoltaics include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium selenide/sulfide. Photovoltaic solar panel is the most commonly used solar technology to generate electrical energy (Togrul, 2009). Two types of PV systems exist in the markets: grid connected or centralized systems and off-grid or decentralized systems. The recent trend is strong growth in centralized PV development with installations that are over 200 kW, operating as centralized power plants. The leading markets for these applications include Germany, Italy, Spain and the United States.

Individual particles of light are called photons. An individual photon is considered to possess a single wavelength depending on its energy content. The range of wavelengths in the solar spectrum is directly due to collection of photons of different energy content. The distribution of photons in a wide energy spectrum has a deciding role in the performance of many solar energy utilization devices (Togrul, 2009).

Figure 2.2: Photovoltaic PV solar panels

2.3.2 Concentrated Solar Power (CSP)

Concentrated solar power systems use mirrors or lenses to concentrate a large area of sunlight, or solar thermal energy, onto a small area. Electrical power is produced when the concentrated light is converted to heat which drives a heat engine (usually a steam turbine) connected to an electrical power generator. Unlike the photovoltaic solar cells, converting energy from sunlight to electricity by CSP systems is based on the application of heat engine rather than photovoltaic effect which is directly transfer photon energy into electricity energy. Concentrating collectors exhibit certain advantages as compared to the conventional flat-plate type (Frenz, 2004). The working fluid can achieve higher temperatures in a concentrator system when compared to a flat-plate system of the same solar energy collecting surface. This means that a higher thermodynamic efficiency can be achieved based on Carnot Efficiency (Frenz, 2004).

The thermal efficiency is greater because of the small heat loss area relative to the receiver area. Reflecting surfaces require less material and are structurally simpler than flat panel collectors (FPC). For a concentrating collector, the cost per unit area of the solar collecting surface is therefore less than that of a FPC (Frenz, 2004).

Owing to the relatively small area of receiver per unit of collected solar energy, selective surface treatment and vacuum insolation techniques are used to reduce heat losses and improve the collector efficiency are economically viable. Their disadvantages are: 1) Concentrator systems collect little diffuse radiation depending on the concentration ratio.

2) Some form of tracking system is required so as to enable the collector to follow the sun. 3) Solar reflecting surfaces may lose their reflectance with time and may require periodic cleaning and refurbishing (Frenz, 2004).

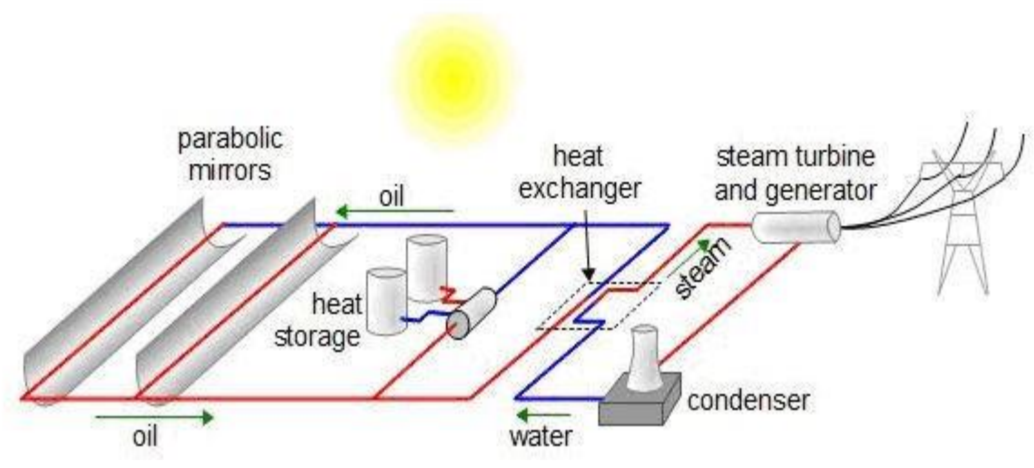

Figure 2.3: Parabolic Concentrated power system

There are four categories of concentration collectors, each of which is discussed below: ***Parabolic trough collectors (PTC)-*** are made by bending a sheet of reflective material into a parabolic shape, a metal black tube, covered with a glass tube to reduce heat losses, is placed along the focal line of the receiver. It is sufficient to use a single axis tracking of the sun thus producing long collector modules. The collector can be orientated in an east–west direction, tracking the sun from north to south (Frenz, 2004).

Linear Fresnel collectors (LFR) - relies on an array of linear mirror strips that concentrate light on to a fixed receiver mounted on a linear tower. The LFR field can be imagined as a broken-up parabolic trough reflector. The main advantage of this type of system is that it uses flat or elastically curved reflectors which are cheaper compared to parabolic glass reflectors. Additionally, these are mounted close to the ground, thus minimizing structural requirements (Frenz, 2004).

Solar towers (Heliostat field collectors) - can be used for extremely high inputs of radiant energy to reflect their incident direct solar radiation onto a common target. This is called the heliostat field or central receiver collector. By using slightly concave mirror segments on the heliostats, large amounts of thermal energy can be directed into the cavity of a steam generator to produce steam at high temperature and pressure (Frenz, 2004).

Parabolic dish reflectors (PDR) - is a point-focus collector that tracks the sun in two axes, concentrating solar energy onto a receiver located at the focal point of the dish. The dish structure must track fully the sun to reflect the beam into the thermal receiver (Frenz, 2004).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

In this Chapter, various instruments, methods and materials were used in assessing and designing of solar energy in Wajir town. Assessment and Designing were carried out separately then Solar Energy resources comprising of Radiation were first recorded for three months, a model design was done using the observed radiation so as to design solar energy for Wajir town. Design based on the daily energy demand assessment of selected such as (Wajir hospital, households and shops) were described. The current research involved quantitative, Field survey and the use of Sunny Design software.

3.2 Area of study

Wajir County is located in North Eastern Kenya, according to National Council for Population and Development (NCPD) (2017), it borders the following counties; Mandera to the North East, the Republic of Somalia to the East, Garissa to the South, Isiolo and Marsabit to the West, and the Republic of Ethiopia to the North West. Wajir County is one of the 47 counties created under the Kenya Constitution 2010. The county is located in the North Eastern region of Kenya between latitudes 3° N 60‘N and 0° 20‘N and Longitudes 39° E and 41° E and covers an area of 56,685.9 km^2. The county comprises of eight sub-counties namely Wajir East, Tarbaj, Wajir West, Eldas, Wajir North, Buna, Habaswein and Wajir South. It is further divided into 28 divisions, 128 locations and 159 sub-locations. The county has 6 constituencies namely Wajir East, Tarbaj, Wajir west, Eldas, Wajir South and Wajir North and has 30 electoral wards. Wajir North and Wajir South constituencies have the largest number of wards at seven (7), and the rest have four (4) each (NCPD, 2017).

Wajir is a Borana word that means coming together, bequeathed to this part of the country because of the different clans and pastoral communities that used to congregate in areas around Wajir town to water their animals from the abundant and dependable shallow wells. Due to its criticality to all major towns in the region, with its abundant water resources and shallow wells and high human traffic, the British officially established Wajir Town in 1912, to serve as their colonial headquarters. Its Centennial Anniversary was marked in 2012 with week-long celebrations amid much pomp and color (NCPD, 2017).

The main source of water is the seasonal Ewaso Nyiro River. Other sources of water include boreholes, shallow wells, pans and dams for human and livestock consumption. Lake Yahud, which is an underground and permanent lake, situated on the periphery of Wajir town provides water for wildlife and quarry activities although the water is saline and not safe for drinking. There are 14,360 shallow wells, 206 water pans and 98 bore holes. The major users of water are livestock at 53% and domestic use at 30% (NCPD, 2017).

WAJIR COUNTY MAP

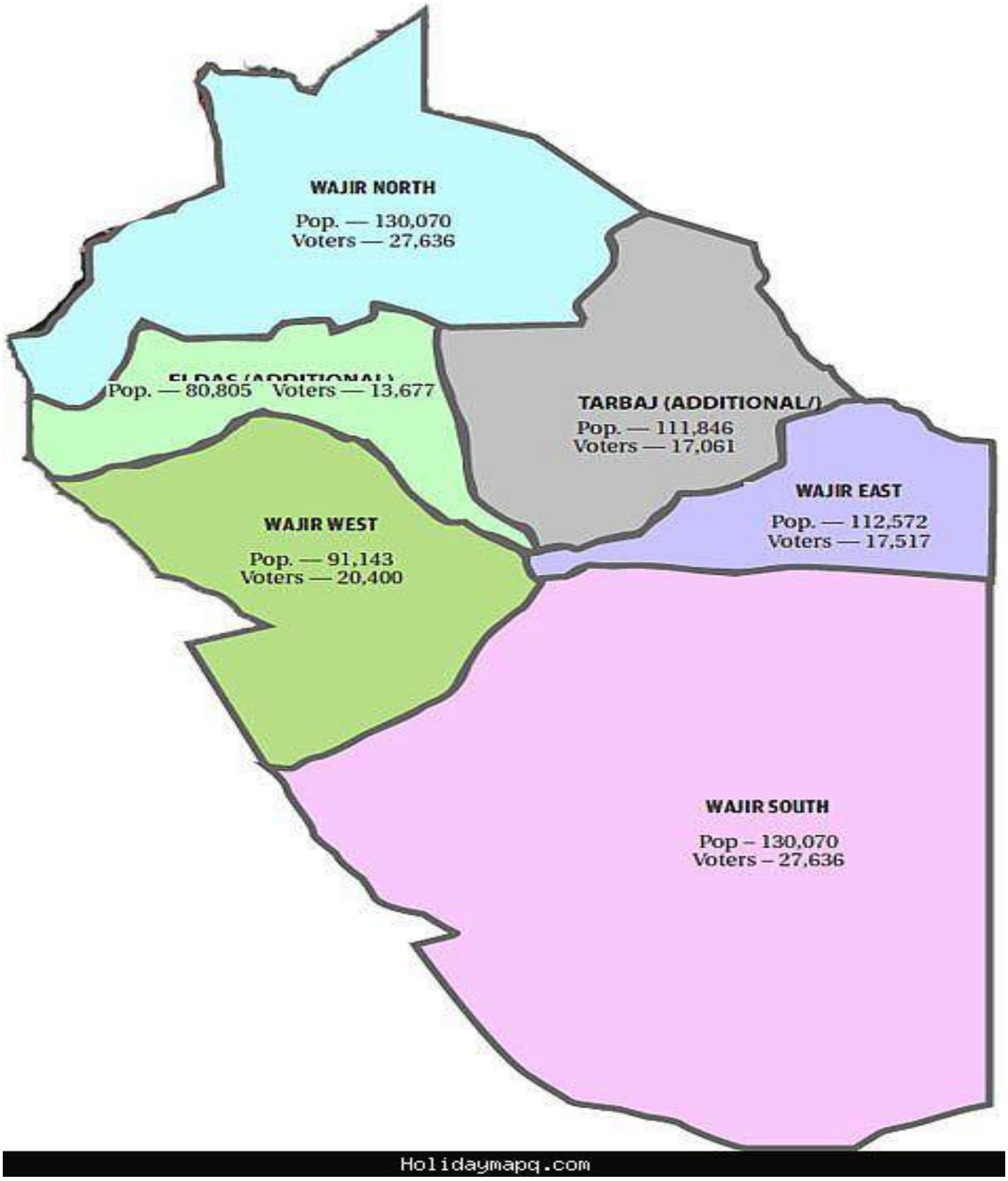

Figure 3.1: Map of Wajir County

3.3 Research instruments

In order to assess solar energy availability reaching the earth's surface, measurements of solar radiation are essential. The solar radiation reaching the earth being direct or diffuse, the component record diffuse so as to know the exact measurement. Data from Wajir County was measured directly with Huksflux Pyranometer. Description of the instrument is outlined in this section.

3.3.1 Pyranometer

Huksflux pyranometer is a solar radiation sensor that is applied in most common solar radiation observations. Complying with the second class specifications of the ISO 9060 standard and the WMO Guide, the Pyranometer was widely used in (agro-) meteorological applications and for PV system performance monitoring. It is a very good alternative to silicon cell (photodiode- based) Pyranometer, which do not comply with the ISO 9060 standard (Saleh, 2000).

It measures the solar radiation received by a plane surface from 180 degrees' field of view angle. This quantity, expressed in W/m^2, is called "hemispherical" solar radiation.

The Pyranometer application was outdoors. Its orientation depends on the application and may be horizontal, tilted (for plane of array radiation) or inverted (for reflected radiation). Measurement was performed aiming at the sun. With the camera aimed at the sun, the measurement value was larger than that in the horizontal position. Solar energy installations are optimized to catch as much sun as possible, typically by aiming them North at an angle depending on the local latitude. The irradiance in W/m^2 was calculated and converted to $MJ/m^2/d$. The instrument recorded solar radiation for a period of three months (October, November and December 2016). The reading was recorded after every hour within the day to get accurate reading.

3.3.2 Estimation of Missing Data

Data from the meteorological department was not complete due to missing of data in some months, therefore equation 1 (simple arithmetic) was used to find the missing data (Omwando *et al.,* 2013)

$$\bar{\bar{x}} = \frac{1}{n}[x_{1,}x_2, x_3 \; and \; x_n] \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

3.4 Software description

Sunny Design Software simulates the operation of the system based on the components chosen by the designer. In this process, the software performs the energy balance calculation based on the system configuration consisting several numbers and sizes of component. The software developed by SMA solar technology, a company based in the United States of America, allows to plan and design PV plants and available in every language with inbuilt sample size calculator and sample estimation tool. It permits, after choosing the main parameters of the PV, to find a good combination for the PV array and the inverter in relation to the performance. In the end the software is able to estimate the potential self-consumption of the energy generated by the PV system.

3.4.1 System configuration setup

All solar systems are designed to solve a particular power problem. There are several design configuration of PV system based on technology and application. In this research PV dc to ac system was used for proper set ups. For the purpose of this research a PV power system without battery bank is considered. The system omit battery and instead uses Tripower inverters which have favorable features that work well with both ac and dc supply. In Wajir, the town uses electricity power from the Kenya power and lighting company therefore PV power system will be used during the day time while during the night power from the Kenya power and lighting company can be used. The hospital uses stand-by generator hence the need to size for hybrid systems for the hospital. The system is needed to supply reliable and uninterrupted electricity to the Wajir town.

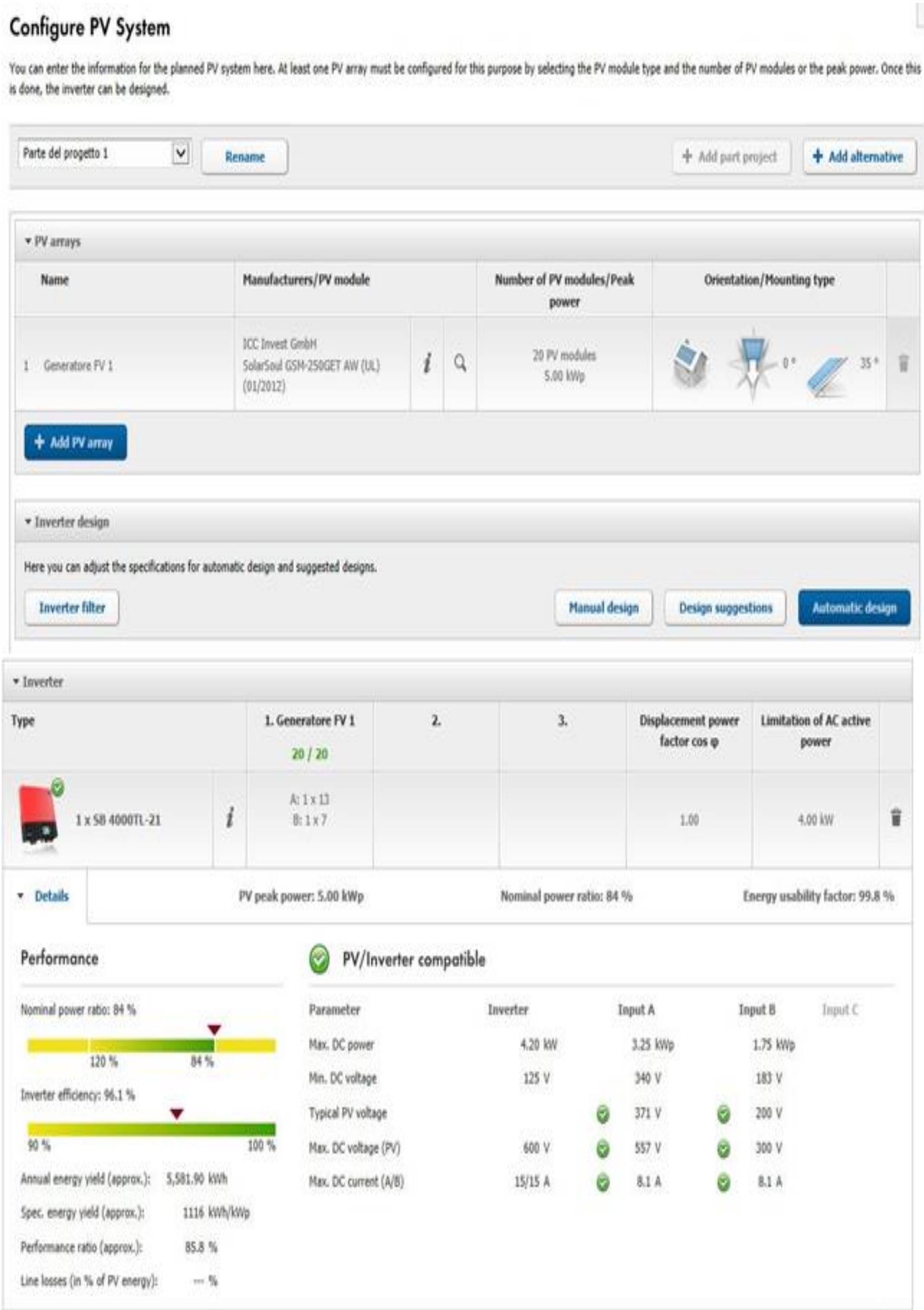

Figure 3.2: PV system configuration

In Figure 3.2, the PV system configuration was determined using the available information in the software. The type of PV modules was selected from database in the software. Subsequently number of PV modules, orientation and mounting type were also selected from the database. The software chooses automatically the best orientation and mounting type for the selected place.

The software also permits the use of manual design of the inverter choosing from a hundreds of SMA products or making a suggestion. It is advisable to use the suggestion of the software because it can find the best combination for the PV plants. It shows main parameters (voltage, electricity, power and nominal ratio performance) of the inverter and the best array for the plant.

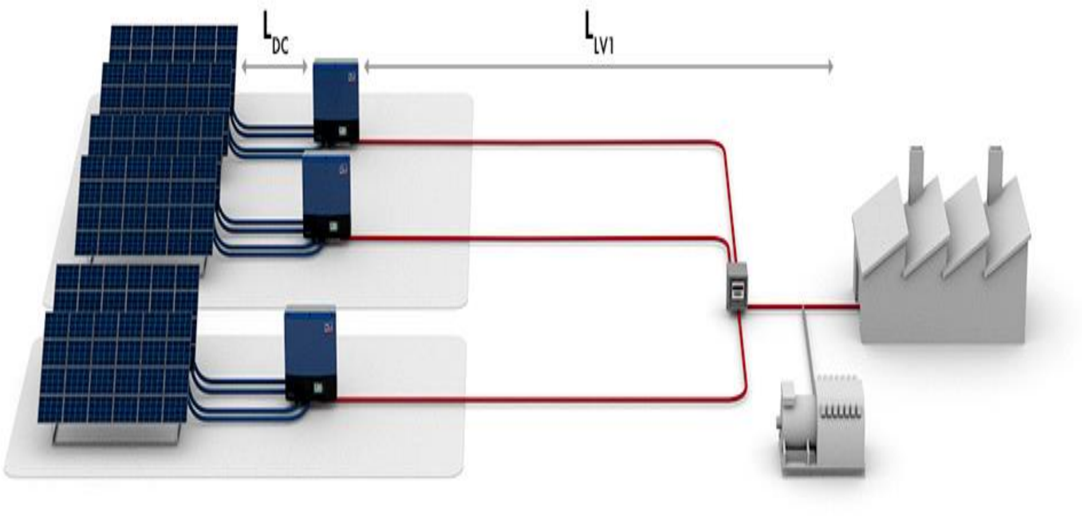

Figure 3.3: Design configuration lay out

In Figure 3.3, the system comprises of PV modules arranged in a systematic layout and connected to the Tripower type inverters. The Tripower is compatible with power from the off-grid (Kenya power and lighting company) and that from the PV energy.

There are different types of PV modules and different types of inverters since every type of module has different characteristics, so as to achieve the best solution. In selecting the best inverter, compatibility and durability was considered since there are different inverters in the database of the software. Tripower inverters have special characteristics such as the ability to display annual energy yield, performance of the system and the active ac power.

The AC active power, the annual energy yield and the specific energy yield are determined from the configuration lay out.

The AC active power (MW) being the power that was introduce in the electric web after inverters, different energy yields comprising of the PV share and any other source of power are known from the set up lay out of the system configuration.

3.4.2 System Design Procedure Using Sunny Design

The system was designed using Sunny Design as follows:

Energy demand for the households, shops and hospitals

Selection of load

Selection of PV system design configuration

Sizing of PV array

Sizing of PV modules

Sizing of inverters

Figure 3.4: System design flow chart

3.5 Determination of design daily load

Daily load was obtained for ease in designing. The energy output from the PV system will vary from time to time during every day therefore proper sizing of the PV system was done. The daily load of the hospital, twenty households and shops were observed. After obtaining the daily load, calculating the exact energy usage per day was possible.

3.5.1 Sizing and specifying PV array

PV sizing using Sunny Design was done with different rating capacity. PV modules are connected in order to generate the desired output. And as such, several units' sizes were put to be considered in the design for optimization of the whole system. The modules are ground mounted. Equation 2 was used to size the PV array required.

$$PV_{array} = \frac{E_{tot}}{SPH \times efficiencies} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Etot: Total Daily energy demand (Wh/d) SPH: Solar

Peak Hour (h/d). = 6.6

PVder: PV derating factor (%) which takes in account: = 80%

System efficiencies= 74%, 94%

3.5.2 Sizing of PV Modules

Equation 3 was used in sizing the number of PV modules. In selection of a PV module, efficiency and the warranty of the module are the two factors considered. The panel used is Canadian Solar CS6P-250PX New Edge (12/2013) for the purpose of market prices, efficiency, warranty and availability of the modules.

Number of strings:	3
PV modules per string:	24
Peak power (input):	18.00 kWp
Typical PV voltage:	656 V
Min. PV voltage:	619 V
Min. DC voltage (Grid voltage 240 V):	150 V
Max. PV voltage:	918 V
Max. DC voltage:	1000 V
Max. current of PV array:	24.9 A
Max. DC current:	33 A

Figure 3.5: Module characteristics

Since the system being designed uses the maximum power point tracker in-built within the Tripower inverter, the input must be equal to output; during the sizing of the PV modules and PV array, module type used is a Canadian Solar Inc. CS6P-250PX NewEdge (12/2013). The module has two strings from two inputs from the inverter. Maximum DC voltage is 1000V while the maximum PV voltage is 918V. The required maximum DC current for the module is 33A.

$$\text{Number of PV modules} = \frac{\text{size of PV array (kw)}}{\text{rating of the pannel (w)}} \qquad (3)$$

3.5.3 Sizing the Inverter

Inverters used are Sunny Tripower type with different Maximum AC active power ranging from 22 kW. The inverter links between the PV system, the distribution network system and the loads therefore the choice of a Tripower inverter in a PV system is dependent on the input and output voltages, the phase type (3-phase or single phase), output kW (power), full load efficiency, operation type and the presence of utility fault protection features. In this research the inverter with the following characteristics are considered so as to attain effective and reliable PV system;

1. D.C input voltage of between 240V and 480V to minimize cable sizes.
2. An alternating current output voltage of 433V, 3 phase.
3. Efficiency at full load of above 95% to minimize losses.
4. Ability to perform maximum power point tracking to minimize the number of panels needed.

Tripower inverter has unique features compared to other inverters. It delivers high yield with efficiency of 98.4% and compatible with many PV modules. It works temperature range of 25-60^{0}C. It has multiple string capabilities unlike other inverters. It has integrated system control inside which monitors and protect the system from over voltage and current and designed with anti-theft system inbuilt, DC surge arrester, flexible optimal display and reactive power availability control system. These characteristics allows the system to be unique and can be used in off-grid and stand-alone PV system.

Table 3.1: Inverter characteristics

Tripower 25kW inverter	Specifications	
Inputs	2(input A and B)	
Max. AC power	25kW	
Max. DC power	25kW	
Grid Voltage	415V(240V/415V)	
Efficiency	98%	

Equation 4 was used to size the inverter.

$$\text{Number of inverters} = \frac{\text{size of PV array (kw)}}{\text{rating of the inverter (kw)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(4)$$

3.6 Cost Analysis

The economical evaluation was calculated based on the inputs of financial aspects, which include the cost of the system components and on the other hand the benefits that would be earned from the system. Payback period was calculated in the results and the annual capital cost was estimated using the Equation 5.

$$Simple\ payback\ period = \frac{\text{total insalled cost} - \text{incentives}}{\text{annual produced kWh} \times \text{energy cost per kWh}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The initial investments required to build the system, annual fixed costs and equipment cost were considered as the payback time for the plants. Market prices for modules and inverters were done before the set-up of the system was done so as to attain payback period

CHAPTER FOUR

RESULTS, ANALYSIS AND DISCUSSION

4.1 Introduction

This chapter contains discussion of the results obtained using the methodologies. The results are discussed independently under the following sub-sections;

1. Quality control test
2. Solar radiation pattern
3. Energy demand and design
4. Cost analysis

4.2 Results from Quality Control Test

4.2.1 Estimation of missing data

The data from the meteorological department were not complete and had some missing values and this contributed to less than 10% of the total observations. Estimation of missing data was therefore applied using Simple Arithmetic Method.

4.3 Results from Solar Radiation

4.3.1 Monthly Radiation for October November and December 2016

From Table 4.1, radiation values for October, November and December 2016 were observed and the minimum recorded monthly value was 6.1 kWh/m^2/day while the maximum value recorded was 7.4 kWh/m^2/day. The data was first recorded in W/m^2 then converted to MJ/m^2/d and finally to kWh/m^2/d. Average daily insolation of Wajir Town for the three months' record was 6.6 kWh/m^2/d. December had the maximum average value of 6.8 kWh/m^2/d followed by October of 6.6 kWh/m^2/d and November with 6.5 kWh/m^2/d. It was noted that December had the maximum average due to a constant clear skies. During the month of December, the town experienced longer hours the availability of the sun.

The long hour sun duration was experienced from day 20 to 28th day of December. In October and November there was significant of cloudiness which makes the values to decrease.

The average of the radiation readings was slightly lower than that of the meteorological which was 6.8 kWh/m2/d. The result concurs with Milanzi 2013, Omwando *et al.* (2013), and Okoola *et al.* (2008) which says that September-November there was cloud cover that affects radiation increase and from December it is hot and dry.

Okoola *et al.,* 2008 stated that cloud cover and raining affects the penetration of solar radiation. During the years 1967, 1972, 1977 and 1997 El Nino and cloud covered mostly during those years affecting the performance of the radiation penetration. In relation to Okoola *et al.,* 2008 the month of December in 2016, radiation penetration was higher compared to November and October 2016 where cloud cover affected the radiation. During the month of December, radiation penetration was high due to long daytime from 7:00 am to 6:30 pm without cloud cover in the sky. The unique weather profile categorized December 2016 as the month with the highest radiation penetration compared to the month of November and October.

Table 4.1: Solar Radiation in Wajir County for a period of three months

	October 2016		November 2016		December 2016		Average
	$MJ/m^2/d$	$kWh/m^2/d$	$MJ/m^2/d$	$kWh/m^2/d$	$kWh/m^2/d$	$MJ/m^2/d$	$kWh/m^2/d$
1	23.76	6.6	23.41	6.5	23.76	6.6	6.6
2	24.45	6.8	23.07	6.4	24.45	6.8	6.7
3	23.41	6.5	23.76	6.6	23.41	6.5	6.5
4	24.88	6.9	23.76	6.6	24.45	6.8	6.8
5	23.41	6.5	24.45	6.8	24.88	6.9	6.7
6	23.06	6.4	23.06	6.4	23.41	6.5	6.4
7	22.72	6.3	22.72	6.3	24.45	6.8	6.5
8	23.41	6.5	23.76	6.6	24.88	6.9	6.7
9	23.76	6.6	23.41	6.5	25.57	7.1	6.7
10	23.41	6.5	23.06	6.4	24.88	6.9	6.6
11	23.41	6.5	23.76	6.6	23.41	6.5	6.5
12	23.76	6.6	23.41	6.5	24.45	6.8	6.6
13	22.29	6.2	23.76	6.6	23.76	6.6	6.5
14	24.45	6.8	22.72	6.3	24.45	6.8	6.6
15	23.41	6.5	24.45	6.8	24.1	6.7	6.7
16	24.88	6.9	23.41	6.5	25.57	7.1	6.8
17	23.41	6.5	23.76	6.6	24.45	6.8	6.6
18	23.06	6.4	22.29	6.2	24.88	6.9	6.5
19	23.41	6.5	21.95	6.1	23.41	6.5	6.4
20	23.76	6.6	23.06	6.4	24.45	6.8	6.6
21	23.41	6.5	23.06	6.4	23.41	6.5	6.5
22	23.41	6.5	23.41	6.5	24.88	6.9	6.6
23	24.45	6.8	23.06	6.4	25.92	7.2	6.8
24	23.76	6.6	22.29	6.2	25.57	7.1	6.6
25	22.72	6.3	23.41	6.5	26.61	7.4	6.7
26	23.41	6.5	23.06	6.4	25.92	7.2	6.7
27	23.06	6.4	23.41	6.5	24.88	6.9	6.6
28	23.41	6.5	22.72	6.3	24.45	6.8	6.5
29	23.41	6.5	23.41	6.5	24.45	6.8	6.6
30	23.76	6.6	24.45	6.8	24.88	6.9	6.8
31	24.45	6.8			23.76	6.6	6.7

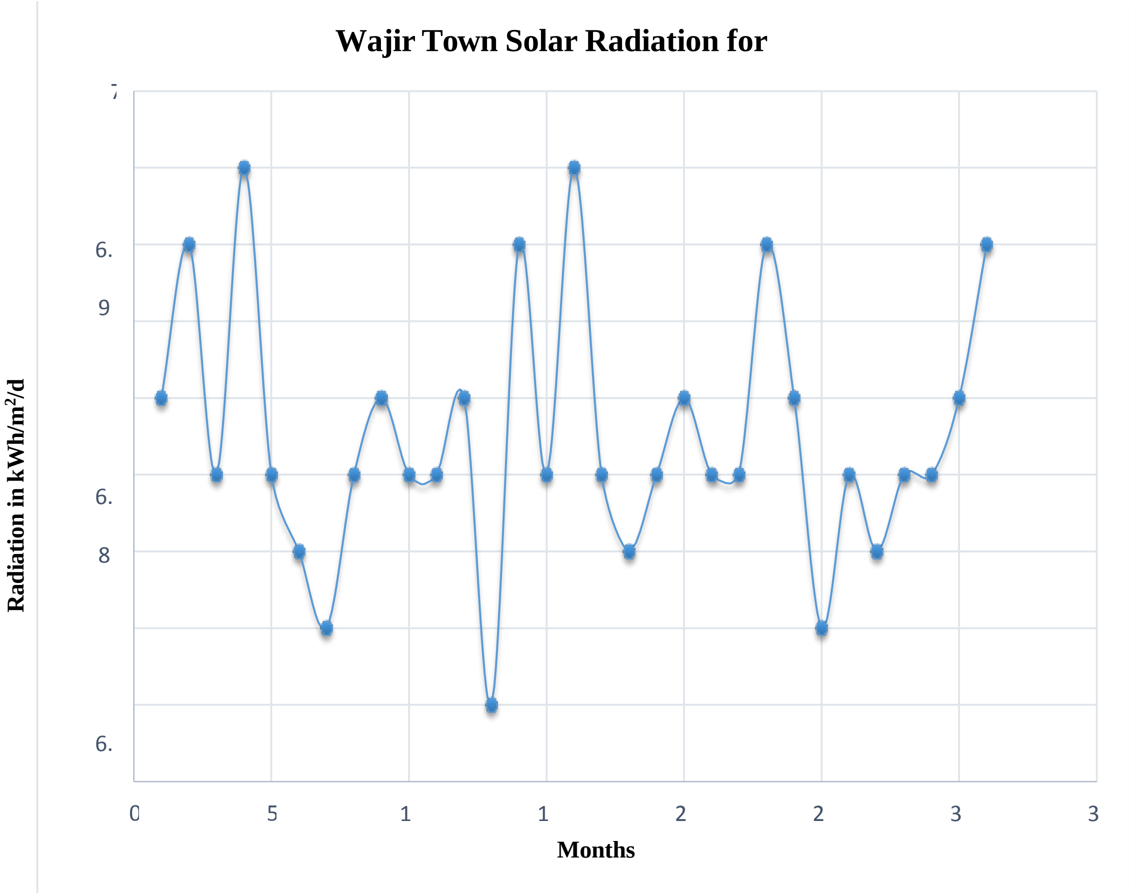

Figure 4.1: Wajir solar radiation for October 2016

Figure 4.1 shows that radiation penetration in October is moderate. The highest recorded was 6.9 kWh/m^2/d and the minimum value observed was 6.2 kWh/m^2/d, throughout the month of October there was cloud cover during the morning session in Wajir town that affected the penetration of solar radiation reaching the earth. September to November there was moderate penetration of solar radiation reaching the earth. Recorded values are in close range. In this month of October, there are six peaks; 2nd, 4th, 14th, 16th, 23rd and 31$^{st.}$ during these peaks there was no radiation hindrance such as cloud covers. In October, Wajir town experienced low penetration of radiation as compared to the month December. Due to the short rain that started late October till early November, penetration of solar radiation was reduced. September to November are rainy seasons (Okoola *et al.*, 2008) but in Wajir town the rain was short and existed only few days therefore the results in October agrees to that of Okoola *et al.*, 2008 and Omwando *et al.*, 2013.

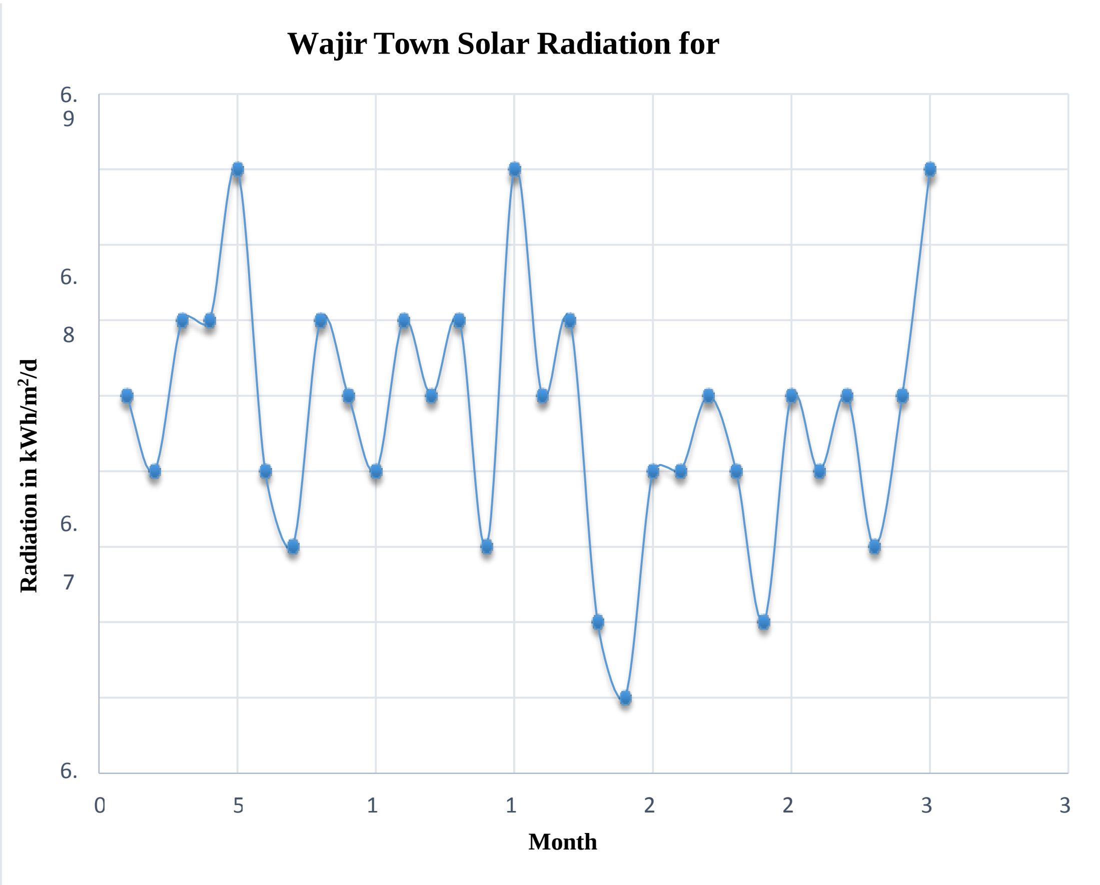

Figure 4.2: Wajir solar radiation for November 2016

Figure 4.2 shows that radiation penetrations are low compared to other months (October and December 2016). The highest value observed was 6.8 kWh/m^2/d while the minimum recorded value was 6.1 kWh/m^2/d. In this month there are three peaks, day five, fifteen and thirty first respectively. (5^{th}, 15^{th} and 3^{st}). During this month, penetration of radiation was low due to the fact that the sky was cloudy for few days and this made low solar radiation penetration on 19^{th} day of the month. After every peak there was scattered clouds formed, therefore November had low penetration of radiation. After date 30^{th} of November the weather changed to hot. Milanzi 2013 shows that the highest radiation peak was received after November, the result confirms that after this month Wajir experienced hot. Most of the days during the month of November there was low values of solar radiation ranging between 6.2 kWh/m^2/d to 6.4 kWh/m^2/d.

The result concurs with that of Milanzi, 2013 which says that during the last days of November the radiation penetration increases as December is ever hot.

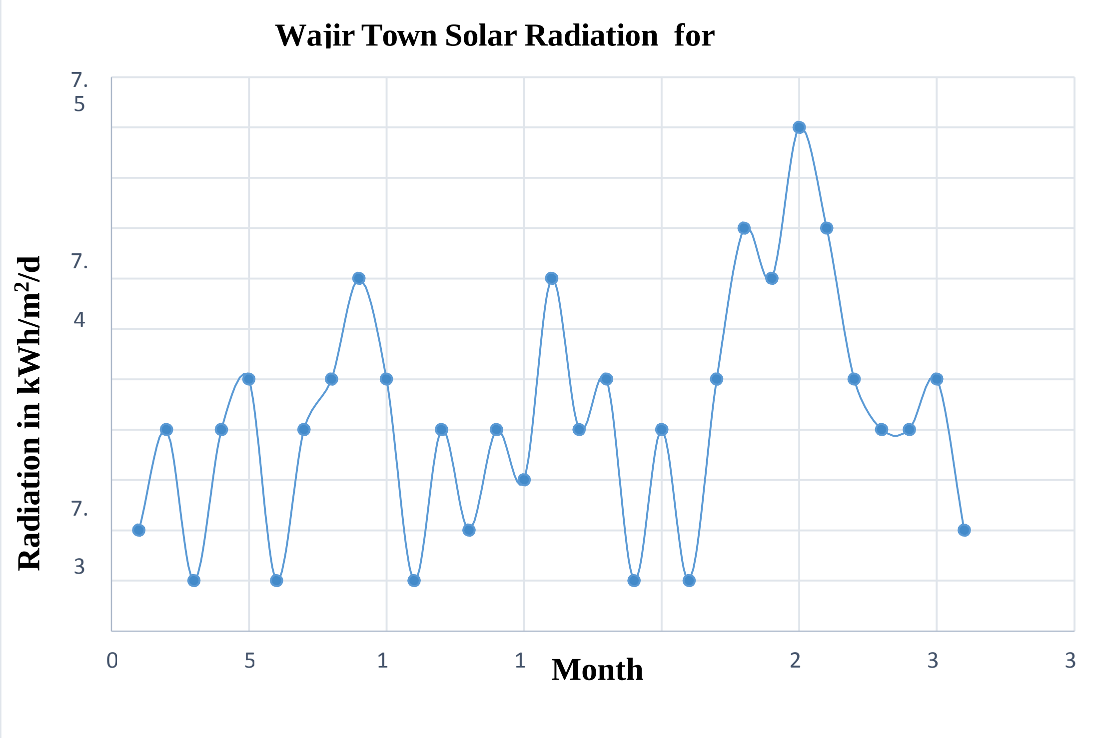

Figure 4.3: Wajir Solar Radiation for December 2016

In Figure 4.3, it was observed that the highest value obtained for December was 7.4 kWh/m^2/d and the lowest value recoded was 6.5 kWh/m^2/d, radiation penetration during this month as compared to the other months was high. A total of 212 kWh/m^2 was observed in this month which equivalent to 762 MJ/m^2. Radiation record for December was increasing gradually day by day. From 11th to 14th, 16th to 21st and 26th to 31st of the month, low values of solar radiation were observed. It is evident that after 21st day, the values keep on increasing until they reached maximum threshold value of 7.4 kWh/m^2/d. The high value was due to lack of cloud cover throughout the day and the sky was clear. During this month, the town experienced total sunlight and radiation was reaching the earth with no obstructions.

December is known for its hot properties, Omwando *et al.*, 2013 confirms that hot and dry is experienced during December to February season. The result from Wajir town agrees that December was the month with highest solar radiation reaching the earth.

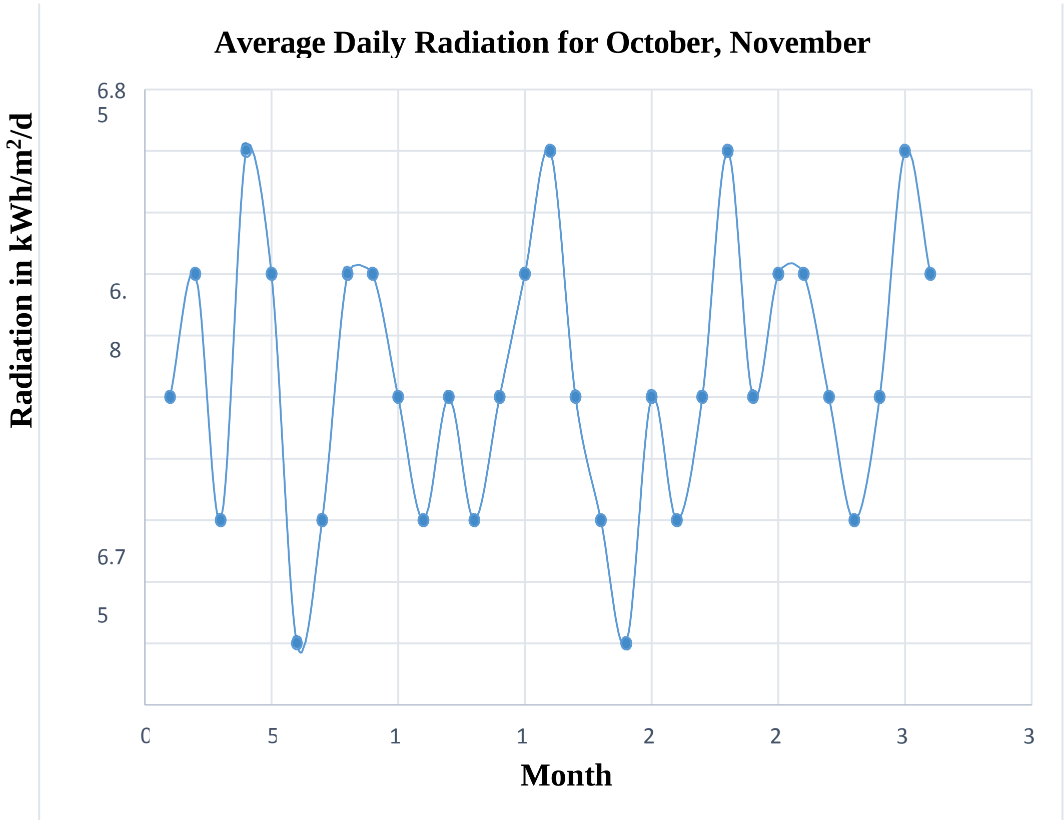

Figure 4.4: Average Daily Radiation for October, November and December 2016

Figure 4.4 depicts the average daily radiation of the three months. It was observed that the maximum average value was 6.8 kWh/m^2/d and the minimum average was 6.4 kWh/m^2/d. It is evident that the region has reliable solar energy potential. The average radiation for the three months was 6.6 kWh/m^2/d and it represents the town of Wajir. When compared the average daily radiation of the three months and that of data recorded from the meteorological department, it is evident that Wajir has an average of between 6.6 kWh/m^2/d and 6.8 kWh/m^2/d.

4.3.2 Monthly Radiation from Meteorological department

Table 4.2: Annual Insolation Averages for Wajir County

Monthly Radiation Averages in kWh/m^2/day (2000-2010)													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Average**
2000	7.4	7.6	6.8	6.1	5.6	4.9	4.8	5.6	6.5	6.1	5.7	6.7	**6.2**
2001	7.3	7.4	7.5	6.5	6.1	5.1	5	6.3	7.4	5.9	5.7	7.3	**6.5**
2002	7.4	7.5	7.6	6.1	6.5	6.5	5.9	6.4	6.9	5.9	7.2	7.2	**6.8**
2003	7.5	7.4	7.4	6.4	6.5	6.2	6.6	7.5	7.2	6.8	7.3	7.1	**7**
2004	7.3	7.6	7	7.5	6.8	7.3	6.8	7.1	7.4	7.4	6.7	7.6	**7.2**
2005	7	7.2	7.5	7.3	6.4	6.5	6.6	6.5	7.6	7.4	6.8	7.3	**7**
2006	7	7.5	7.4	6.2	6.8	7.2	7.3	7.5	7	7.4	6.8	7.6	**7.1**
2007	7.6	7.7	7.6	6.7	6.4	6.9	6.1	6.6	6.6	6.2	6.8	7.1	**6.8**
2008	7.6	7.7	7.4	6.3	6.3	6.6	6.5	6.8	6.6	7.3	6.5	6.7	**6.8**
2009	7.4	7.6	7.5	6.7	6.9	6.9	6.4	5.6	6.8	7.3	6.6	7.3	**6.9**
2010	7.8	7.7	7.3	6.9	7.4	6.5	6.6	6.6	6.4	6.8	7.1	7	**7**
Average	7.4	7.6	7.4	6.6	6.6	6.4	6.3	6.7	7	6.8	6.7	7.2	**6.8**

Table 4.2 shows the insolation values from meteorological department for Wajir town (2000-2010). It was observed that the minimum recorded monthly value was 4.8 kWh/m/d and maximum value of 7.8 kWh/m/d. February had the maximum average of 7.6 kWh/m/d while July had the minimum of 6.3 kWh/m/d. The penetration was high during the month of February due to the hot and dry season from December to February. During June- August season low penetration was observed due to cold dry season. Kenyan seasons are classified into: December- February, dry hot season; March-May, long rains season; June-August, dry cold season and September-November, short rains season (Okoola *et al.*, 2008). The result confirms that Wajir receives high solar radiation during December-February and low penetration during June-August season.

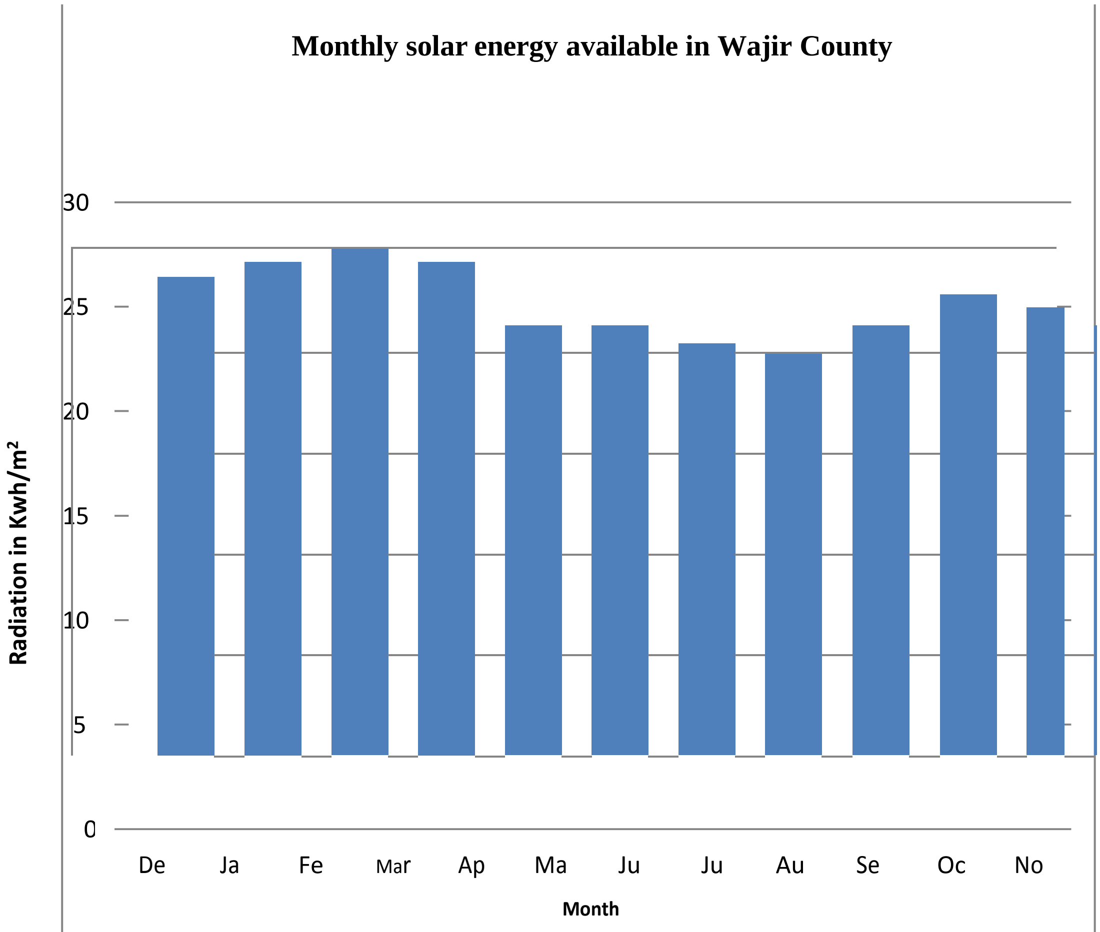

Figure 4.5: Monthly Solar energy availability for Wajir Town 2000-2010

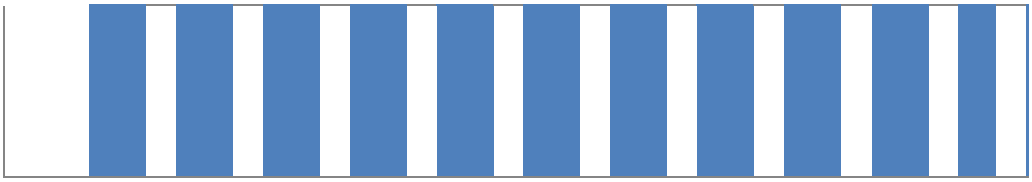

Figure 4.5 above shows that February has the highest solar penetration of 298.14 kWh/m^2/d while July has the lowest penetration of 247.07 kWh/m^2/d. Due to cold and dry season from June to August, the month of July (from July 2000 to July 2010) receives the lowest penetration. From September to November, radiation penetration is moderate as compared to June to August. The result confirms that the region receives its highest radiation in the month of February and least value in the month of November. This information is crucial and important with regards to which month is appropriate for maximum harvest solar energy resource.

4.4 Seasonal Radiation Analysis

The climate system in Kenya has four seasons namely: December-February, hot season; March-May, rainy season; June-August, cold season and September-November, short rains season (Okoola *et al*., 2008).

4.4.1 December-February seasons

From the observation in Table 4.3, January has the highest value followed by February then December. This means that the month of January from the year 2000 to 2010, the highest recorded value was 7.8 kWh, February from 2000 to 2010 the highest recorded was 7.7 kWh and December from 2000 to 2010 was 7.6 kWh.

The result reveals that during December to February season solar radiation reaching Wajir town is high.

Table 4.3: Radiation values for December-February season 2000-2010

	Dec	Jan	Feb
Maximum recorded value (kWh)	**7.6**	**7.8**	**7.7**
Minimum recorded value (kWh)	**6.7**	**7**	**7.2**
Mean daily value (kWh)	**7.2**	**7.4**	**7.6**
Monthly mean value (kWh)	**223.2**	**229.4**	**230**

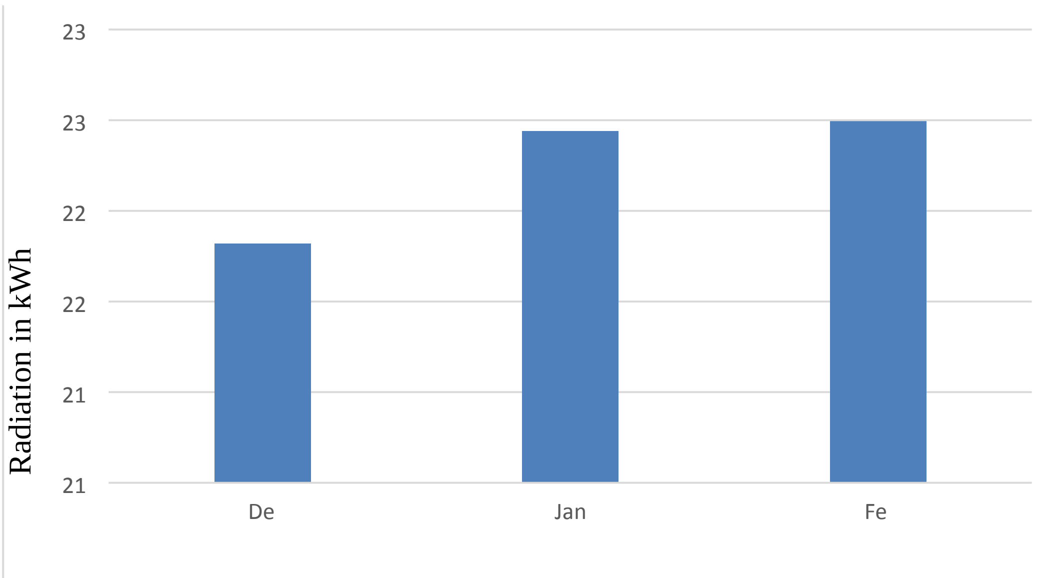

Figure 4.6: December-February Season in kWh/month 2000-2010

Figure 4.6 shows different radiation received on the months of December, January and February. These months are grouped as Dec-Feb season. From the observations, during December to February season solar radiation reaching Wajir town was high. The month of February receives the highest value of 230 kWh/m^2, followed by January with a value of 229.4 kWh/m^2 and lastly December with value of 223.2 kWh/m^2, totaling to 682.6 kWh/m^2 for the entire season. During this season solar energy harvest is possible since the amount of solar radiation is a determinant of the output yield of the energy.

4.4.2 March-May seasons

From the observation in Table 4.4, March has the maximum value recorded followed by April then, May. This means that the month of March from the year 2000 to 2010, the highest recorded value was 7.6 kWh, April from 2000 to 2010 the highest recorded was 7.5 kWh and May from 2000 to 2010 was 7.4 kWh. The result shows that during March - May season solar radiation reaching Wajir town is moderate as compared to December – February season.

Table 4.4: Radiation values for March-May season 2000-2010

	Mar	Apr	May
Maximum recorded value (kWh)	**7.6**	**7.5**	**7.4**
Minimum recorded value (kWh)	**6.8**	**6.1**	**5.6**
Mean daily value (kWh)	**7.4**	**6.6**	**6.6**
Monthly mean value (kWh)	**229.4**	**198**	**204.6**

Table 4.4 shows different radiation received on the months of March, April and May. These months are named as March - May season. From the observations, during March to May season, solar radiation reaching Wajir town was moderate. The month March receives the highest value of 229.4 kWh/m^2, followed by May with a value of 204.6 kWh/m^2 and lastly April with value of 198 kWh/m^2, totaling to 632 kWh/m^2 for the entire season. During this season the weather changes from hot and dry and therefore penetration of solar radiation is moderate and solar harvest is still moderate.

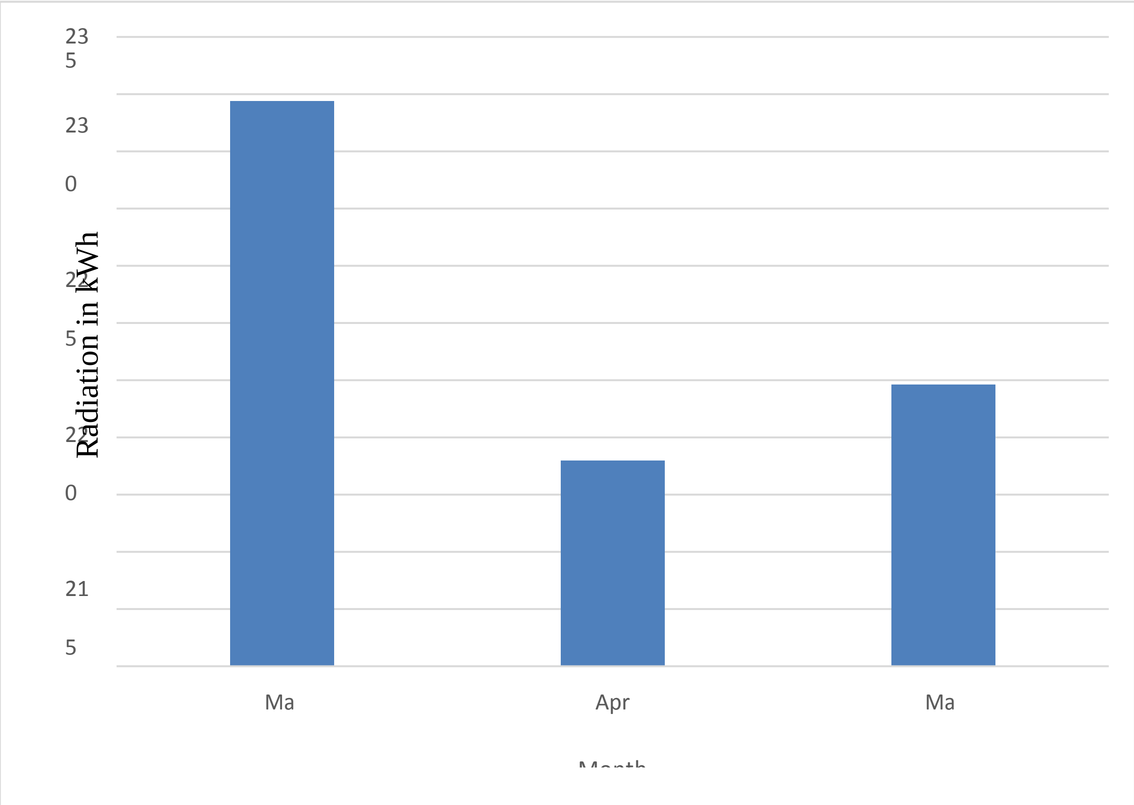

Figure 4.7: March - May Season in kWh/month 2000-2010

4.4.2 June-August Season

From the observation in Table 4.5 August has the maximum recorded value followed by July and June with the same value. This means that the month of August from the year 2000 to 2010, the highest recorded value was 7.5 kWh, July from 2000 to 2010 the highest recorded was 7.3 kWh and June from 2000 to 2010 was 7.3 kWh. The result shows that during June-August season solar radiation reaching Wajir town was moderate due to cold and dry throughout the season.

Table 4.5: Radiation values for June-Aug season 2000-2010

	June	July	Aug
Maximum recorded value (kWh)	**7.3**	**7.3**	**7.5**
Minimum recorded value (kWh)	**4.9**	**4.8**	**5.6**
Mean daily value (kWh)	**6.4**	**6.3**	**6.7**
Monthly mean value (kWh)	**192**	**195.3**	**207.7**

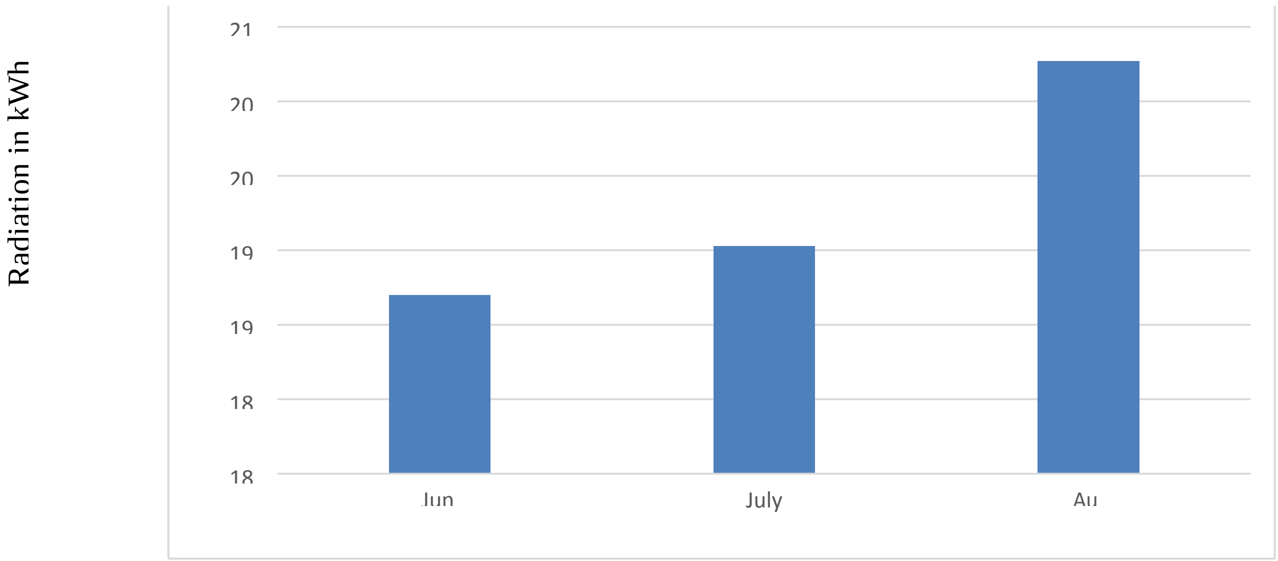

Figure 4.8: June- August season in kWh/month 2000-2010

Figure 4.8 shows different radiation received on the months of June, July and August. The radiation received during these months are season dependent. June has the least radiation penetration while August has the highest penetration. From the observations, during June to August season solar radiation reaching Wajir town was moderate. The month of August receives the highest value of 207.7 kWh/m^2, followed by July with a value of 195.3 kWh/m^2 and lastly June with value of 192 kWh/m^2, totaling to 595 kWh/m^2 for the entire season. During this season radiation reaching Wajir town is slightly lowest as compared to other seasons. This is because the weather change results low radiation penetrations and factors such as cloud. The cloud cover hinders total penetration of radiation. During this season, fluctuations of radiation is observed and therefore a guideline to follow when solar harvest is needed.

4.4.3 September-November Season

From the observation of Table 4.6, September and October have the highest values of 7.6 kWh each, while November with 7.3 kWh. The result shows that during September- November season solar radiation reaching Wajir town was moderate. Figure 4.9 shows different radiation received on the months of September, October and November. These months are grouped as September to November season. From the observations, during September to November season solar radiation reaching Wajir town was moderate as compared to June – August and March – May seasons. The month of October receives the highest value of 210.8 kWh/m^2, followed by September with a value of 210 kWh/m^2 and lastly November with 207.7 kWh/m^2, totaling to 628.5 kWh/m^2 for the entire season. During this season, solar energy harvest is possible since the amount of solar radiation input is a determinant of the output yield of the energy.

Table 4.6: Radiation values for Sep-Nov season 2000-2010

Sep	Oct	Nov		
Maximum recorded value (kWh)	7.6	7.6	7.3	
Minimum recorded value (kWh)	6.4	5.9	5.7	
Mean daily value (kWh)		7	6.8	6.7
Monthly mean value (kWh)		**210**	**210.8** **207.7**	

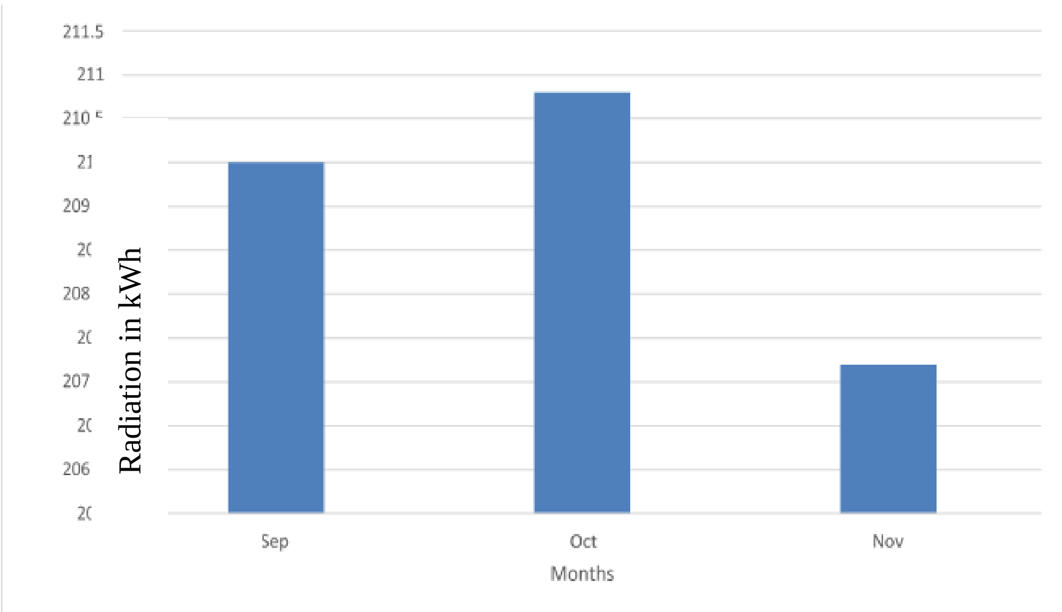

Figure 4.9: September-November season in kWh/month 2000-2010

4.5 Energy Demand

4.5.1 Available Energy Demand

Comparisons were made between the available energies (electricity, charcoal, firewood and kerosene) and the use of solar energy. There are 88574 households in Wajir. 3039 households use electricity, 14948 households use kerosene for lighting, and 155 households use fuel woods or firewood, 26296 households' uses solar directly and indirectly, (Knoema, 2017).

Table 4.7: Households' energy demand

Fuel type	Quantity (kg)	Net Calorific Value	Consumption(kWh)	Average Efficiency stove %	Effective Consumption (kWh)
Firewood	8 (155)	4.0	4960	7.5	372
Kerosene	0.5(14948)	12.83	95891.42	30	28767.43
Charcoal	2(10000)	8.2	164000	11	18040

Table 4.7 shows different energy consumed daily by Wajir County. The households depend heavily on firewood, Kerosene and Charcoal. 155 households used 8 kg of firewood with effective daily consumption of 372

kWh/day, out of the total households 14948 used 0.5 kg of kerosene for lighting during the night with effective consumption of 28767.43 kWh, and 10000 households used charcoal for cooking with effective daily consumption of 18040 kWh. This is evident that Wajir Town heavily relay on fossil fuel and therefore the need to utilize the available solar energy resource so as to cut constant depending on fossil fuel.

4.5.2 Daily energy demand for households

Table 4.8 was used to record for daily energy consumption for households. Daily usage of electricity for twenty households where observed for the estimation of energy demand for 5-hour lightning from 120 lamps of 60 W each, 12 of the houses have a 6-hour fan of 75 W, and 14 of the houses also had a 5-hour TV set of 15 W. During the survey of the reading and recording of the daily energy consumptions it was noted that the households preferred using 60 W rating of the lamps therefore it is advisable for the town to adopt the use of low rated lightings so as to safe energy.

4.5.3 Daily energy demand for small scale business center (shop)

Table 4.9 was used to record daily energy demand for small scale business center (shops). Twenty shops of each 5-hour light from three lamps of 60 W each, a 4-hour fan of 75 W, a 12 hour thirty-five refrigerator of 80 W and a 10 hour two mobile charges of 4 W each where surveyed.

4.5.4 Daily energy consumption for the health clinic center

Table 4.11 was used to record daily energy consumption for the health clinic center. Wajir town has one main referral hospital with 11-hour lightning from one thousand five hundred lamps of 36 W each, a 10 hour seven hundred fifty fans of 75 W each, 24 hours twenty refrigerators of 80 W and 6 hour two hundred and fifty desktop computers of 55 W were recorded to estimate usage of electricity for the hospital.

4.5.5 Solar energy design for Wajir Town using Sunny Design Software

The Table 4.8 shows the total energy demand for the households. The total energy demands in kwh/day for the twenty households are 42.45 kWh/day and 15494.25 kWh/yr. 300 households were used for the design.

20 Households = 42.45 kWh/d

300 Households?

After obtaining the total energy demand for the twenty households, estimation of the energy demand for three hundred households was done using the Sunny design tool so as to model the total energy demand for three hundred households

$$\frac{300\ households \times 42.45\ kWh/d}{20\ households} = 636.75\frac{kWh}{d} \approx 232413.75kWh/yr$$

Table 4.8: Daily energy consumption for households

Appliances	Quantity (Pieces)	Amount of energy per unit (W)	Usage hour per day	Daily use of electricity (kWh per day)
Lightings	120	60	5	36
Fun	12	75	6	5.4
TV	14	15	5	1.05

Table 4.9: Energy demand for the shops

Appliances	Quantity	Amount of energy per unit	Usage hour per day	Daily use of electricity (KWh per day)
Lightings	300	60	5	90
Fun	1(20)	75	4	6
Refrigerator	35	80	12	33.6
Mobile charger	2(20)	4	10	1.6

Due to the high temperature condition the region uses electric Fun continuously for four hours. It is clearly shown in table 10. The total energy demand in kwh/day for the twenty shops was 132 kWh/day and 48180 kWh/yr. Four mosques were observed with only lamps for lightning and fans. Each has a 4 hour twelve lamps of 60W each and a 6 hour 8 Funs of 75W each. It is shown in table 10 with the total daily use of the electricity in kilowatt-hour per day for the mosque. The total energy demand in kwh/day for the four mosques are 17.28 kWh/day and 6307.2 kWh/yr.

Table 4.10: Daily energy consumption for the mosques

Appliances	Quantity (pieces)	Amount of energy per unit (W)	Usage hour per day	Daily use of electricity(KWh per day)
Lightings	12(4)	15	4	2.88
Fun	8(4)	75	6	14.4

Wajir Town is served by one health Centre that as shown in Table 4.11. The total energy demand in kwh/day for the four mosques were 17.3 kWh/day and 6314.5 kWh/yr.

Table 4.11: Daily energy consumption for the health center

Appliances	Quantity (piece)	Amount of energy per unit (W)	Usage hour per day	Daily use of electricity(KWh per day)
Lightings	1500	36	11	594
Fun	750	75	10	562.5
Refrigerator	20	80	24	38.4
Desktop	250	55	6	82.5

4.5.6 Energy Demand for the Households and mosques

Total demand in a year for 300 households = 32413.75 kWh/yr.

Total demand in a day for =636.75 kWh/day

Total demand in a day and year for the 4 mosques=17.3kWh/day and Average daily sum =6.6 h

$$\frac{238728.25\ \mathrm{kWh/yr}}{6.6\ \mathrm{h}} = 36170.95\ \mathrm{kW/yr}$$

$$\frac{36170.95\ \mathrm{kW/yr}}{365} = 99.1\ \mathrm{kW}$$

$$\frac{99.1\ \text{kW}}{0.8 \times 0.96 \times 0.74} = 174.4\ \text{kW}$$

Using Equation 3, the number of modules are 488 and the rated capacity for each PV module used in the study was 250 W whose initial capital cost is $195. The rated 250 W was selected since the capacity of the solar panel in Watts will directly affect the cost, as solar panels are usually priced (and compared) in dollars per Watt. Watts are related to the output of each module; for instance, using a 100 Watt panel operating under ideal conditions will make the system to have more modules. Again the issue of market availability and cost comes in thus the need to select affordable modules from repetitive manufactures. 476 PV modules were used during the design with peak wattage of 116.16 kWp. The modules are ground mounted due to the land availability in Wajir town.

The maximum available PV energy was 232413.75 kWh/yr. Using Equation 4 the total number of inverters were 5 inverters with rating capacity of 25 kW. Inverters used are five Sunny Tripower type with Maximum AC active power of 22 kW, Maximum DC power 25.55 kW. It has nominal power ratio of 91%. The inverters are compatible with the size of the PV array. It has efficiency of 91.2% with integrated DC surge arrester.

4.5.7 Energy Demand for the Shops

Total demand in a year = 48180 kWh/yr.

Average daily sum = 6.6 hrs.

$$\frac{48180\frac{kWh}{yr}}{6.6\ h} = 7300\frac{kW}{yrs}$$

$$\frac{7300\frac{kW}{yr}}{365} = 20\ kW$$

$$\frac{20\ kW}{0.8 \times 0.96 \times 0.74} = 35.2\ kW{\sim}Array\ size$$

Using Equation 3, the total number of modules were 100 modules. The rated capacity of each PV module used in the study is 250 W whose initial capital cost is \$195. PV modules are connected and as such, several units' sizes were put to be considered in the project for optimization of the whole system. 100 PV modules were used during the design. The modules are ground mounted. Using Equation 4 the total number of inverters was 1 inverter with rating capacity of 20 kW. Inverter used was only one of Sunny Tripower type with Maximum AC active power of 20kW, Maximum DC power 25.00 kW with maximum input voltage of 1000V and rated voltage of 600 V. It has nominal power ratio of 110%.

4.5.8 Energy Demand for the Health Centre

Using Equation 3, the total number of modules were 956 modules. The rated capacity of each PV module used in the study is 250 W whose initial capital cost is $195. 956 PV modules was used during the design. The cost of a diesel generator depends on its size. For the present study, the DG capacity is rated as 304 kW of 380 kVA. Therefore, even though the design proposed in this study ensures the guaranteed electricity source from diesel generators, the aim always remains to reduce their operating hours. The fuel consumption by the generator was 80.0 I/h or 3.50 kWh/l. The fuel cost is considered to be $0.85 per liter. The lifetime of DG is 15000 operating hours. The generator model is designed in such a way that it can operate in standalone mode to feed the load. The DG output is utilized to meet the load. Using equation 4 the total number of inverters are 11 inverters with rating capacity of 25 kW.

$$\frac{466251\ kW/yr}{6.6\ h} = 70644.4\ kW$$

$$\frac{70644.1\ kW/yr}{365} = 194\ kW$$

$$\frac{194\ kW}{0.8 \times 0.96 \times 0.74} = 341.36\ kW$$

$$size\ of\ the\ PV\ array \sim 70\%\ of\ 341.36\ kW = 239\ kW$$

Inverters used are eleven Sunny Tripower type with Maximum AC apparent power 25.00 kVA, Rated power 25.00 kW. The inverters are compatible with the size of the PV array. It has efficiency of 98.4% with integrated DC surge arrester and has DC input voltage of up to 1000 V. Availability of electricity within the hospital must be twenty four hours a day therefore the need to size for standby generator that can be used when the power shortage from Kenya Power and lighting company arise, total energy demand for the hospital was 466251 kWh/yr., Tripower inverter is therefore be the best choice since it has compatibility effects to work under such unstable power conditions. The inverters have smart and innovate features to detect when the output performance from either the PV modules or the generator become unstable.

4.6 Cost-Benefit Analysis

The cost of design and installation of PV for 300 households, 20 shops and hospital was determined. Economic viability to solve the problem of rural electrification in the County of Wajir and Cost-Benefit analysis of the PV has been done.

4.6.1 Estimation of project life.

For accurate estimation of the cost, the project life time was considered to be 25 years since it's the warranty period of the solar modules. The warranty period of the inverters was 20 years.

4.6.2 Estimated investment cost for 300 households

Table 4.12: Investment cost of individual components for the households.

Items	Quantity	Cost from manufacture ($)	Total cost ($)	O&M cost	Total costs ($)
25 kW inverter	5	2877	14385	-	14385
Panel CS6P-250PX New Edge (12/13)	489	195	95355	-	95355
Mounting Cost	489	-	-	-	20000
Sub total					149740
Estimated cost LV distribution network	10% of sub total				14974
Grand Total					**164714**

4.6.3 Estimated cost for the Health Centre

Table 4.13: Investment cost of individual components for the Health Centre

Items	Quantity	Cost from manufacture ($)	Total cost ($)	Shipping cost (10%)	O&M cost	Total costs ($)
25 kW inverter	11	2877	31647		-	31647
Panel CS6 P- 250PX New Edge (12/13)	956	195	186420		-	186420
Genset (380 kVA)	1					20000
Mounting Cost	956	-	-	-	-	10000
Sub total						248067
Labour, Engineering	10% of sub total					24806.7
Total						272873.7
Estimated cost LV distribution network						10000
Grand Total						**282873.7**

4.6.4 Estimated cost for the shops

Table 4.14: Investment cost of individual components for the shops

Items	Quantity	Cost from manufacture ($)	Total cost ($)	O&M cost	Total costs ($)
20 kW inverter	1	2877	2877	-	2877
Panel CS6P-250PX New Edge (12/13)	100	195	19500	-	19500
Mounting Cost	100	-	-	-	7000
Sub total					29377
Labour, Engineering & Supervision cost	10% of the sub total				2937.7
Total					32314.7
Estimated cost LV distribution network					10000
Grand Total					42314.7

4.6.5 Economic viability of solar PV for the households and shops

The economic viability using Simple Payback Analysis for the household and shop were determined using Equation 5. The total energy, payback period, replacement cost and operation and maintenance cost was calculated to determine the energy cost in dolor per kWh.

Energy cost ($/kWh) = Cost of the system ($) / Energy generated

Total Cost of the system = $ 20702

Replacement cost=$650000 for the period of 25 years

O &M cost= 10% of 207028=$20702.8

Total cost=650000+207028+20702.8=$878928.7

Energy generated for 25 years =7014843.75 kWh

Energy cost ($/kWh) = $878928.7/7014843.75= US0.13/kWh

Simple payback period= total installed cost- Incentives / annual produced KWh × energy cost per kWh.

Simple payback = 207028 / 280593.75 x$0.13

Simple payback period= 6 years

4.6.6 Economic viability of solar PV for the Hospital

The economic viability using Simple Payback Analysis for the hospital was determined using Equation 5. The total energy, payback period, replacement cost and operation and maintenance cost was also calculated to determine the energy cost.

Energy cost ($/kWh) = Cost of the system ($) / Energy generated (kWh)

Total Cost of the system = $ 282873.7

Replacement cost=700000 for the period of 25 years

O &M cost= 10% of

282873.7=28287.37

Total cost=700000+282873.7+28287.37= $ 1011161.07

Energy generated for 25 years =11656275 kWh

Energy cost ($/kWh) = $1011161.07/11656275= US0.10/kWh

Simple payback period= total installed cost- Incentives / annual produced KWh × energy cost per kWh.

Simple payback = 282873.7/466251 x $0.10

Simple payback period= 7

years

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

This chapter provides conclusion and recommendations from the study. It has been shown from the results of the study that there is abundant solar radiation resource which is not being utilized in Wajir town. This abundant solar radiation can be harnessed and be put into various uses such as electricity generation by the use of PV systems. The work involved solar radiation assessment, sizing and cost benefit analysis of the use of solar PV systems in Wajir town.

5.1 Conclusions

Results revealed that Wajir town has an average daily insolation of 6.6 kWh/m^2 however; the amount of solar energy available is season dependent with December-February season receiving the highest daily amount of 7.4 kWh/m^2 and June-August season receiving the least daily amount of 6.5 kWh/m^2. The total energy demand for twenty households, twenty shops and the maim hospital are 15494.25 kWh/yr, 48180 kWh/yr and 466251 kWh/yr respectively. The rated capacity of each PV module used in the study is 250 W whose initial capital cost is $195. In designing and sizing for appropriate and reliable solar PV system for the hospital, the need for a standby generator was necessary since the hospital requires power availability throughout the day and night therefore hybrid system was sized. The cost of a diesel generator depends on its size. For the present study, the diesel generator (DG) capacity is rated as 304 kW of 380 kVA. Therefore, even though the design proposed in this study ensures the guaranteed electricity source from diesel generators, the aim always remains to reduce their operating hours. The fuel consumption by the generator is 80.0 I/h or 3.50 kWh/l. The fuel cost is considered to be $0.85 per liter. The lifetime of diesel generator is 15000 operating hours. The generator model is designed in such a way that it can operate in standalone mode to feed the load and its output is utilized to meet the load. The required peak wattage capacity for the hospital, shops and the households are 239 kW, 25 kW and 122.1 kW respectively with no battery since the design used Tripower inverters which are smart and can work in both ac and dc applications. The cost of the sizing and installation of PV for 300 households, 20 shops and hospital was determined and summed at 48990240 Kenya shillings including line voltage (LV) distribution network.

The findings show that the system is affordable and will reduce a lot of environmental degradation since most of the population in the county uses Charcoal and firewood for their daily activities. The cost of extending the national electricity grid to Wajir County is expensive as compared to the installation of PV mini-grid system. Therefore, suggestion for further development for mini-grid application is recommended however, from the research it can be concluded that, the town needs an alternative method to utilize the available solar energy in the region.

Economic viability under the circumstances to solve the problem of rural electrification in the county of Wajir and cost-benefit analysis of the PV has been done and the calculated feed-in-tariff of US 0.13 USD/kWh with a payback period of 7 years for the households and 6 years for the hospital using the simple payback analysis were done. The feed-in-tariff is close to the Kenyan revised feed-in-tariff of USD 0.2 cents/kWh, while Sunny Design analysis gave a payback period of 5 years. Therefore, this study can be used to initiate PV mini-grid system for Wajir town by any willing investor.

5.2 Recommendations

Local government (county) should play an important role in promoting PV mini-grid systems during their decision making and planning for infrastructure development. The county government in collaboration with local non-governmental organizations should help implement alternative energy system. The research could only achieve results for the Wajir town which is in one of the six constituencies and therefore suggest for further improvement to the whole of Wajir County.

The capacity of the PV system can be increased in the future to increase the solar energy and decrease the rapid consumption of fossil fuel so as to achieve maximum economic efficiency of the system.

Hybridization of PV system with other available renewable energy such as biomass and wind can be considered for further research. In remote areas, renewable resource like the biomass is found in abundant. As an area where its people are mainly pastoral farmers, cow dung is found in abundant. This would make biomass energy to be easily generated and integrated in the system to reduce the fuel dependence. Wind energy assessment in the region should be conducted so as to introduce wind/solar hybrid system.

Financial institutions should give appropriate loans to the local and international investors so as to make use of this abundant resource.

Future research need to be done more especially on the study of the wind power to consider solar wind hybrid systems, research on the application of biomass energy for electricity generation and implementation of policies that harness renewable energy resources for the benefit of Wajir county.

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APPENDICES

Appendix i (a): Wajir Hospital

System

956 xCanadianSolarInc.CS6P-250PX New Edge (12/2013) (PV array 1)

10 xSTP20000TL- | **1xSTP20000TL-**

PV design data

Peak	95 239.00	Energy usability	99.9
Number of PV	1	Line losses (in % of PV energy):	---
Nominal AC power of the PV inverters:	220.00 kW	Used PV	70
Active power	92.1	PV share of the energy supply	70
Max. Available PV	416.97	PV share of the energy supply (during	70

Appendix i (b): Evaluation of design out look

10 xSTP20000TL-30(PV system section1)

Peak power: 217.50 kWp

Total number of PV modules: 870

Number of PV inverters: 10

Max. DC power (cos φ= 1): 20.44 kW

Max. AC active power (cos φ= 1): 20.00 kW

Grid voltage: 415V (240V /415V)

Nominal power ratio:

Dimensioning

STP20000TL-30

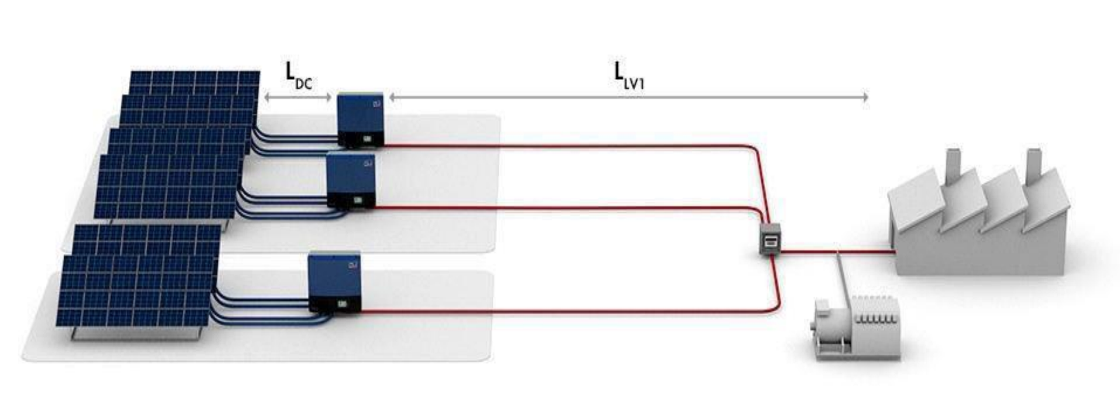
	3	1
	22	21
	601V	574V
	568V	542V
	150V	150V
	841V	803V
	1000V	1000V
	24.9A	8.3A
	33A	33A

Appendix i (c): Line Voltage Wire Sizing for the Households

Overvie

	D	L	Tot
Power loss at	989.22	1.75	2.74
Rel. power loss at	0.38	0.80	1.17
Total cable	880.00	110.00	990.00
Cable cross-	1,	2,	1, 5

Graphi



DC

	Cable material	Single length	Cross section	Voltage drop	
Subproject1					
10x STP 20000TL-30	Copper	10.00 m	1, 5	2.3 V	0.37 %

Li

Su

Appendix i (d): Genset Details

Overall view

	Gensets	Load profile
Max apparent power	380kVA	71553VA
Max. active power	304kW	71553W
Quantity of the genset	1	
Average genset efficiency	1.71 kWh/l	

Design conditions

The minimum power of the genets, adjusted for the load, takes into account an additional power reserve that can be provided by the genets. A load-related minimum power of 110% means a power reserve of

Load-related minimum power	100 % (of the maximum power requirement)
Minimum PV power to be expected	30 % (of the possible PV power with no clouds)

Maximumpermissible PVinverterpower

The genset reference power takes into consideration the design conditions and the gensets that are

Genset reference power for PV dimensioning	380.00 kVA
Resulting max. PV inverter power	228.00 kVA

Detailed list of the gensets

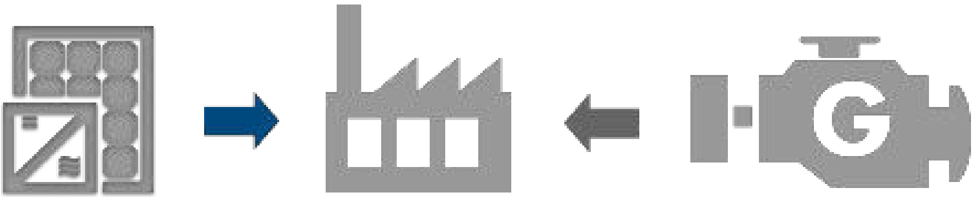
Name	Apparent power	Active power	Fuel consumption at	Genset efficiency at
Genset 1	380 kVA	304 kW	86.9 l/h	3.50 kWh/l

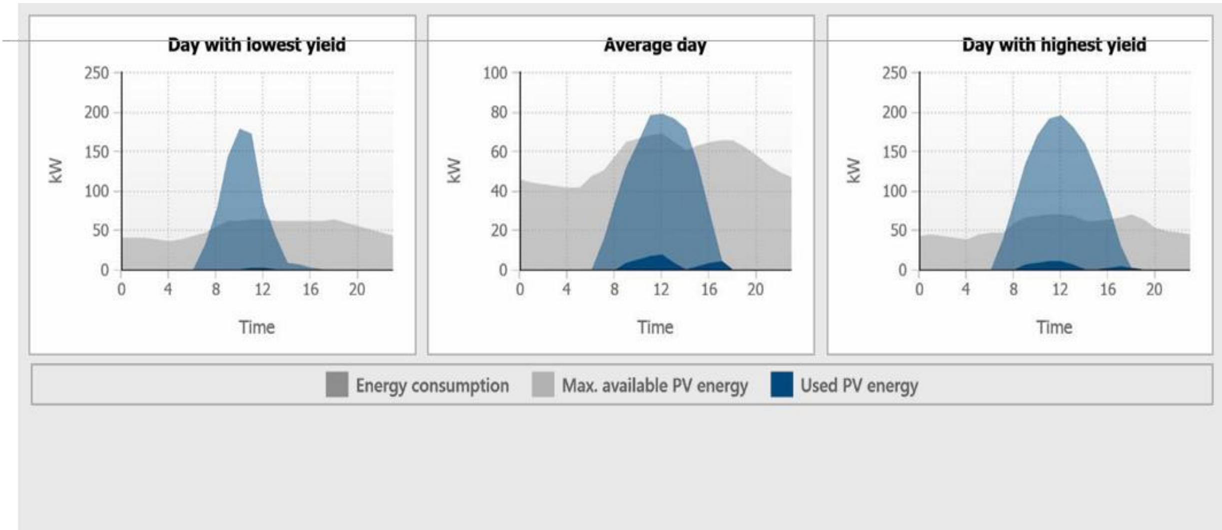
Appendix I (e): Energy Supply Details

Annual energy consumption

466 MWh

Annual energy generation of the	**454.67MWh**
Fuel consumption per year(approx.)	**266,304 l**
Used PV energy	**11,583.96kW**
Annual fuel savings (approx.)	**0l**
PV share of the energy (total)	**70%**
PV share of the energy (during the day)	**70%**





Appendix ii (a): Wajir Town Households

Tel: +254724355163

mohamedelmi18@gmail.com designed by mohamed diyad elmi

Project name: Location:Kenya/Wajir

Grid voltage: 240V (240V /415V)

System

489 xCanadianSolarInc.CS6P-250PX New Edge (12/2013) (PVarray 1)

 **7xSTP15**  **1xSTP15**

PV design data

	4		
Peak	122.2	Annual	213.4
Number of	8	Energy usability factor	10 0%
Nominal AC power of the PV inverters:	120. 00	:Performan	1746
Active	98.	Line losses (in	-
		Unbalan	0.0

Appendix ii (b): System Design for the Hospital

Project name:

Location: Kenya/Wajir
Ambient temperature:
Annual extreme low temperature: 17 °C Average high Temperature: 31 °C Annual extreme high temperature: 39 °C

7xSTP15000TL-30(PV system section1)

Peak power:

Total number of PV modules: Number of PV inverters:

Max. DC power (cos φ= 1):

Max. AC active power (cos φ= 1) Grid voltage:

106.75 kWp 427
7

15.33 kW

15.00 kW

240V (240V /415V)

STP15000TL-30

PV design data

Input A:PV array 1

44x Canadian Solar Inc. CS6P-250PX New Edge (12/2013), Azimuth angle: 0 °, Tilt angle: 15 °, Mounting type: Ground mount
Number of strings:

PV modules per string: Peak power (input):

Typical PV voltage: Min. PV voltage:

Min. DC voltage (Grid voltage 240 V):

	Input A:	**Input B:**	
	2	1	
	22	17	
	601V	464V	
	568V	439V	
	841V	650V	
	1000V	1000V	
	16.6A	8.3A	

Appendix ii (c): PV Design Data

Project name:

Location: Kenya/Wajir
Ambient temperature:
Annual extreme low temperature: 17 °C Average high Temperature: 31 °C Annual extreme high temperature: 39 °C

1xSTP15000TL-30(PV system section2)

STP15000TL-30

Peak power:	15.50 kWp
Total number of PV modules:	62
Number of PV inverters:	1
Max. DC power (cos φ= 1):	15.33 kW
Max. AC active power (cos φ= 1):	15.00 kW
Grid voltage:	240V (240V /415V)

PV design data

Input A:PV array 1

44x Canadian Solar Inc. CS6P-250PX New Edge (12/2013), Azimuth angle: 0 °, Tilt angle: 15 °, Mounting type: Ground mount

	Input A:	**Input B:**
Number of strings:	2	1
PV modules per string:	22	18
Peak power (input):		
Typical PV voltage:	601V	492V
Min. PV voltage:	568V	464V
Min. DC voltage (Grid voltage 240 V):		
	841V	688V
	1000V	1000V
	16.6A	8.3A
	33A	33A

Appendix ii (d): Cable Sizing for the hospital

Overview

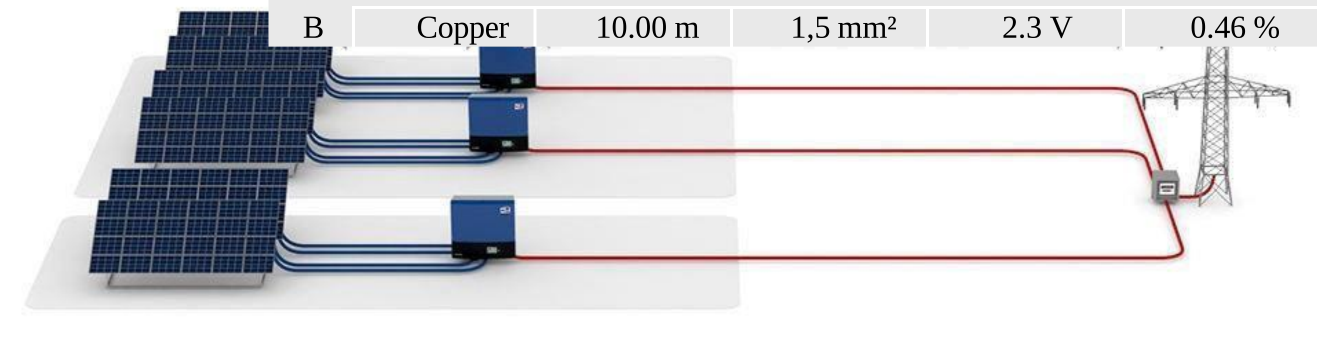
	DC	LV	Total
Power loss at nominal	539.57 W	1.19 kW	1.73 kW
Rel. power loss at rated	0.40 %	1.00 %	1.40 %

Total cable length

Cable cross-sections

	Cable	Single	Cross	Voltage	Rel.powerlo
A	Copper	10.00 m	1,5 mm²	2.3 V	0.37 %
B	Copper	10.00 m	1,5 mm²	2.3 V	0.48 %
A	Copper	10.00 m	1,5 mm²	2.3 V	0.37 %
B	Copper	10.00 m	1,5 mm²	2.3 V	0.46 %

Graphic



DC cables

Subproject1

	Cable	Single length	Cross section	Line	Rel.powerloss
7x STP 15000TL-30 PV system section 1	Copper	10.00 m	1,5 mm²	R: 38.222 XL: 0.750	1.00 %
1x STP 15000TL-30 PV system section 2					
1x STP 15000TL-30 PV system section 2	Copper	10.00 m	1,5 mm²	R: 38.222 mΩ XL: 0.750 mΩ	1.00 %

Appendix ii (e): Energy Yield per Month