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Feasibility study of a sustainable power system for health facilities

Case study of Kolandoto hospital-Tanzania

Master's Thesis in Master degree programmes:
Electrical Power Engineering
Sustainable Energy Systems

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Gothenburg, Sweden 2016

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Cover: Picture from Solar PV installation at Kolandoto hospital, Photo by Martin Skilbred.

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Abstract

Solar photovoltaic is strongly proven for cutting down greenhouse gases emissions and environmental destruction problems that the world is facing today due to the use of non-renewable energy sources. Tanzania considered in this study is also experiencing these challenges with imbalance and unreliable electrical power supply more precisely in health facilities. Therefore, this study aimed to investigate and evaluate ways solar photovoltaic (PV) can be used to improve reliability of existing power supply in health facilities in Tanzania.

This research adopts an exploratory case study approach with a qualitative method for collecting and analysing the data. The case chosen was Kolandoto Hospital-Tanzania. The methods used for collecting data are measurement, participatory observation, participatory workshops, interview and documentation. The empirical findings have been analysed and used in calculations of the solar PV components that can be integrated in existing power system. The modelling of hybrid of solar PV and existing power system is carried out by use of HOMER software to get the optimal size of solar PV components.

The results show that solar PV with backup system interconnected with power grid and diesel generator is feasible, and it provides solutions to energy security problems at Kolandoto hospital. Appropriately configuration is designed and proposed for selected emergency health appliances considered as critical loads in this report.

The use of energy efficiency devices, replacement of old electrical equipments and exploitation of thermal solar for heating purposes are recommended to support the proposed solar PV system and to reduce further the electricity bills. In the future without budget and regulations constraints, net metering and expansion of the designed system to cover total load of the hospital will be more cost effective.

Keywords: Grid, Solar photovoltaic systems, Health facility, Electricity system supply, Kolandoto hospital, Tanzania, Hybrid of solar PV, Grid connected system.

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List of abbreviations and acronyms

AGM: Sealed Glass Mats
AICT : African Inland Church of Tanzania
AIDS: Acquired Immune Deficiency Syndrome
BIPV: Building Integrated Photovoltaic Modules
CdTe: Cadmium Telluride
CHP: Cogeneration of Heat and Power
CIGS: Copper Indium Gallium Selenide
CIS: Copper Indium Selenide
CO: Carbon Monoxide
CO_2: Carbon Dioxide
CPI: Consumer Price Index
CPV: Concentrated Photovoltaic
c-Si: Crystalline Silicon
CSP: Concentrated Solar Power
DC: Direct Current
DHI:Diffuse Horizontal Irradiance
DOD: Depth of Discharge
EWURA: Energy and Water Utilities Regulatory Authority
FLA: Flooded Lead Acid
GC: Gel Cell
GDP: Gross Domestic Product
GEF: Grid Emission Factor
GHI: Global Horizontal Irradiance
GTI: Global Tilt Irradiance
LED: Light Emitting Diode
HIV: Human Immunodeficiency Virus
HOMER: Hybrid Optimization Model for Multiple Energy Resources
I_{sc}: Short Circuit Current
LA: Lead Acid
LCOE: Levelised Cost of Electricity
MEM: Ministry of Energy and Minerals
MPP: Maximum Power Point
MPPT: Maximum Power Point Tracking
NGO: Non-Government Organisation
NO_X: Nitrogen Oxides
NPC: Net Present Cost
OM: Operations and Maintenance
PM:Particulate matter
PPA: Power Purchase Agreement
PSMP: Power System Master Plan
PV: Photovoltaic
PWM: Pulse Width Modulation
REA: Rural Energy Agency

SO_2: Sulfur Dioxide
DNI: Direct Normal Irradiance
SOC: State of Charge
TANESCO: Tanzania Electric Supply Company
TB: Tuberculosis
TCF: Trillion Cubic Feet
TF: Thin Film
TGDCL: Tanzania Geothermal Development Company Limited
TPDC: Tanzania Petroleum Development Corporation
UHC: Unburned Hydrocarbon
VRLA: Valve Regulated Lead Acid
ZECO: Zanzibar Electricity Corporation

1 Introduction

1.1 Problem statement

The source of many environmental problems that the world is facing today such as climate change, global warming and deforestation; is not far from the energy system we use. Clean and renewable energies have strongly proven and promoted to be a viable and reliable solution to abate climate change and global warming. In order to solve both electricity demand and environmental problems, Tanzania concerned in this study is experiencing challenges of developing its energy infrastructure and integrating renewable energy sources in its current power supply.

Fossil fuel, hydro, wind, geothermal and solar are the main anticipated energy sources to increase electricity supply in health facilities, schools, residential houses, commercial buildings, industries, etc. However, electricity demand is far higher than the electricity production in Tanzania. Therefore, there is a lot of effort required to boost production of renewables to meet the electricity demand and reduce the fossil fuel share in electricity generation. To achieve these targets, there must first be proper mechanism to take in charge some limitations such as availability of stable power supply, infrastructure, environment and national energy policy strategy.

Kolandoto hospital in Tanzania, used as case study, is a typical example where unpredicted power outages due to load shedding by utility company are a challenge. A diesel generator which is expensive in long run and presents negative environment impacts is used at Kolandoto as a solution to power outages. Since the hospital management intends to find a sustainable and optimal solution to reduce cost and risks imposed by current energy system; it is essential to know possible available renewable energy resources that can sustain the electricity supply and meet the hospital demand. The hospital is located in a village called Kolandoto, about 15km outside of Shinyanga town which is the regional capital for Shinyanga region in north western of Tanzania.

1.2 Aim

The aim of the thesis is to investigate and evaluate solar potential energy that can improve power security in health facilities in Tanzania. A solar power system to sustain current electricity power supply at Kolandoto hospital will be designed and proposed.

1.3 Research questions

Some of the possible questions that this research project seeks to answer are:

- How solar energy potential can sustain electricity power supply in health facilities, schools, residential houses, commercial buildings in Tanzania?
- What are the limitations of using effectively renewable energy sources in Kolandoto area to reduce the gap between electricity production and demand?
- How solar power system can be part of a reliable solution to meet the electricity power demand at Kolandoto hospital?

1.4 Scope

The task is to investigate potential renewable energy resources in Tanzania. Assessment of available renewable energy sources at Kolandoto that can be used to improve reliability of current power system will be performed. Solar PV system that can be integrated in the existing power supply at Kolandoto hospital will be designed and evaluated based on its sustainability and technical merits. Tanzanian energy regulations and hybridized system finance will be main indicatorsin decision making.

1.5 Objectives

The objectives of the thesis are to:

- Identify the potential of sustainable energy available that can alleviate the gap between electrical demand and production capacity.
- Promote the use of renewable energy source option to improve reliability of power in health facilities.
- Improve social welfare, economy, and services in health facilities, case Kolandoto hospital.
- Support electrification policy of developing countries.

2

Background

2.1 Tanzania geography and economy

Since April, 26^{th} 1964, Tanganyika and Zanzibar were joined together to create the United Republic of Tanzania as one sovereignty country. Today, the Republic of Tanzania has in total 30 administrative regions, where 25 are located on mainland former Tanganyika and 5 are on the island namely Zanzibar. It is the largest country of the East Africa nations, surrounded by Zambia, Malawi and Mozambique in the south; Kenya and Uganda in the north; Democratic republic of Congo, Rwanda and Burundi in the west and the Indian Ocean in the east. The geographical location of Tanzania lies between the latitude 1° S and 11 45' south of the equator and the longitude 29° 20' E and 40°38' east of Greenwich [5].

The total projected population of Tanzania in 2014 was 47.4 millions with a growth rate of 2.9 per year according to Tanzania national panel survey conducted from 2012 to 2013.The population of Tanzania is dominated by youth, around 14.8 million aged between 15 and 35 years, where 84.5 % are economically active and 15.5% are not economically active. The total surface area of the country is 947,303km^2. Dar-es-Salaam is the capital city, and the official languages are Swahili and English [6].

Tanzania's economy has constantly kept strong record of growth rate, 7.3% and 6.9% in 2012 and 2013 respectively, whereas recently in 2015 was 7.1%. The economy of the country is largely based on the agricultural production, 70% of total production is exported, and the same sector generates 75% of total employments. However 28.2% of Tanzanians are still under poverty according to the latest household budget survey (2011/12) [5].

Agriculture, forestry, fishing and hunting were counted for 31.5% of national GDP in 2014 while GDP for electricity, gas and water sector was 1.3%. In favour of fiscal and monetary policy, declining of fuel prices and good food situation inflation has not fluctuated a lot over the past years. For example in 2013 and 2014 CPI inflation were 7.9 and 6.8% respectively, while currently is expected to be 5.6% [7].

Kolandoto hospital later on considered as case study in this report, is located in a village called Kolandoto that has a population of about 10,000 inhabitants. The village is at 15km from Shinyanga town, and the later is the city of Shinyanga region, one of 30 Tanzania's administrative regions positioned in the North West part of Tanzania. Or, roughly two hours by car from Mwanza (second largest city) situated along the Lake Victoria. Shinyanga region has approximately 1,5 million population.

Kolandoto hospital was initiated in 1913 by a couple of American missionaries namely Rev. William Maynard and Dr. Nina Maynard. The hospital is currently owned by African Inland Church Tanzania (AICT) and can be classified as a medium health facility because it has the capacity of holding 168 impatiens. The hospital lies on 27,000m^2 surface area approximately and it comprises of different compartments precisely three operations theatres, maternity, paediatric ward, reproductive child health, pharmacy, administration block, etc.

Kolandoto hospital power source is twofold, first is supplied by TANESCO through national grid and second for 36kW local diesel generator that operate for emergencies cases. Generally the electricity from grid is unreliable due to high frequency of outages and unstable voltage. The occurrence of electricity outages is approximately one to two hours seven days per week. Diesel generator used as back up during the electricity outage is operated manually and supply power in some part of the hospital such as operation theatres, wards, and administration block. The direct associated drawbacks of using diesel generator are high running cost and local emissions.

2.2 Energy sector in Tanzania

This sub chapter gives an overview of the energy sector of the United Republic of Tanzania, discussing the current status of electricity production, primary energy supply, energy consumption, institutional systems and stakeholders involved in managing and regulating Tanzania's energy sector as well as energy resources potentials.

2.2.1 Overview of energy sector in Tanzania

The energy sector of the United Republic of Tanzania is pivotal to the Tanzania's economy, given its systemic link to other sectors of the economy such as transportation, manufacturing, agro-processing, housing and urbanization, mining and IT services.

Considering electricity production, 1717GWh are from hydro, includes production from pumped storage plants, 2566GWh are from gas, 1222GWh are from oil and 15GWh from solar photovoltaic use. Thus, the total electricity domestic supply (2013) was 5574GWh for local generation plus 59GWh imported in neighbouring countries. The power supply losses accounted by 1140GWh, meaning that only 4836GWh of electricity are consumed [1].

Considering share of total primary energy supply excluding electricity trade, the energy balance of Tanzania is dominated by biomass-based fuels particularly fuel-wood (charcoal and firewood) accounted for 85% of total primary energy, 10.7% from oil, 3.5% from natural gas, 0.6% from hydro and 0.2% from coal but peat and oil shale are aggregated with coal [1].

Considering only electricity generation from renewable and waste energy sources, 1717GWh are generated by hydro, 15GWh from solar PV plus 21GWh form primary solid biofuels. Despite the average wind speed of 10m/s available in Tanzania and other renewable energy sources potentials such geothermal, municipal and industrial wastes, electricity from those clean energy potentials sources is not yet exploited [1].

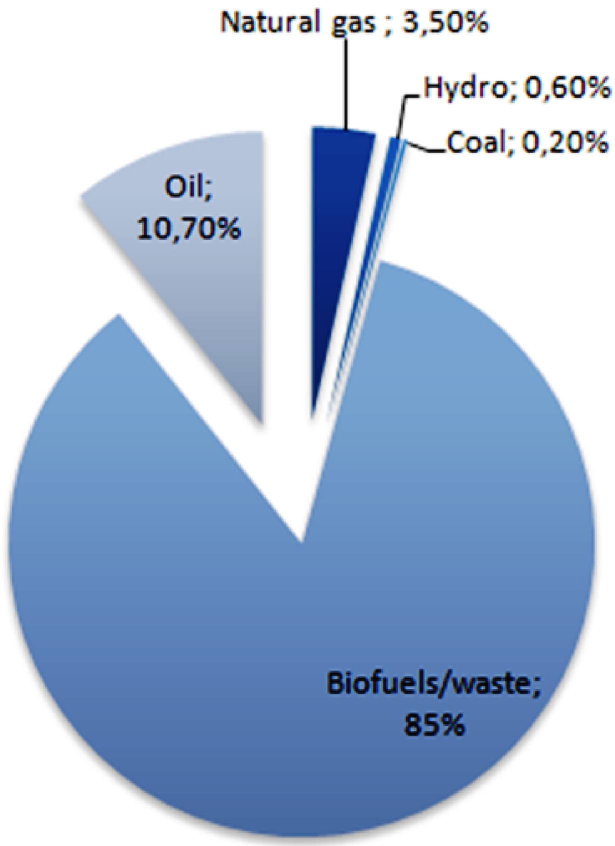

Figure 2.1: Share of total primary energy supply, 2013 [1]

Even if the country has a large deposits share of natural gas, Tanzania faces challenges to prove oil reserves. This makes Tanzania to continuously rely on the imported thousands tonnes (ktoe) of petroleum products for example liquefied petroleum gases (69 ktoe), motor gasoline (529 ktoe), jet kerosene (130 ktoe) other kerosene (53 ktoe) fuel oil (403 ktoe) and gas/diesel (1398 ktoe) per year(2013) [1].

Regarding electricity consumption, Tanzania still has low electricity consumption per capita compared to some countries. In 2013, Electricity consumption per capita for Tanzania was 0.09MWh/capita while Kenya and Iceland have 0.17 and 54.7MWh/-capita respectively. Making reference to the Power System Master Plan (PSMP) 2012-2035 indicated that Tanzania would reach an electrification rate 75% for Tanzanian households by the year 2033. Currently the growth rate of the electricity demand is between 10 to 15% per year, and in 2014 the peak demand was about 905MW [5]. In short, Tanzania's power installed capacity is estimated at 1,583MW (2014) composed by hydro, natural gas power plants and liquid fuel power plant [8].

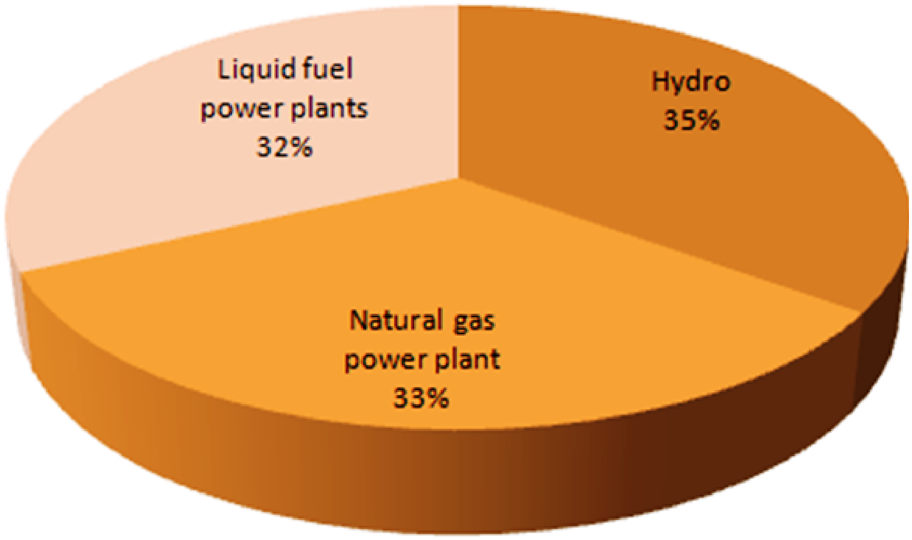

Figure 2.2: Share of power installed capacity

In additional to installed capacity, Tanzania imports about 16MW of power from neighbouring countries; Kenya, Uganda and Zambia. Up to 2014, only about 36% of the country's population has the access to electricity, 20% and 16% in urban and rural areas respectively. In order to meet the electricity demand, some people obtain power from stand-alone diesel generation, solar photovoltaic (PV), and several mini-hydro and mini grid power operated by local NGOs and faith based groups. But also the government initiate to increase utilization of natural gas for power generation, and diversity to other sources like wind, geothermal, coal, and solar.

2.2.2 Energy sector institutions and stakeholders

The main public sector institutions involved in managing and regulating Tanzania's energy sector include:

Ministry of Energy and Minerals (MEM): The ministry is mandated to set policies, strategies and law for sustainability of energy and minerals resources to improve socio-economic development of the country. Particularly for energy sector, MEM is also responsible to provide guidance to enhance energy services like reliability, efficiency, cost effectiveness, and environmental way to other stakeholders for example

TANESCO, EWURA, REA, private companies and financiers [8].

Tanzania Electric Supply Company (TANESCO): TANESCO is a parastatal organization under MEM, Its main responsibilities are to generate, transmit, distribute and sells the electricity to Tanzania Mainland. From 1980, TANESCO supplied bulk power to the Zanzibar State. Fuel and Power Corporation using a 132kV submarine cable of 38km with the capacity of 45MW [5]. Zanzibar Electricity Corporation (ZECO) is the one responsible for the distribution in the regions of Ugunja and Pemba (Zanzibar) [9].

Energy and Water Utilities Regulatory Authority (EWURA): EWURA is an autonomous, multi-sectorial regulatory authority established by the Energy and Water Utility Regulatory Authority Act cap 414 of the laws of Tanzania in 2001.It is responsible for the technical and economic regulation of Tanzania's electricity, petroleum, natural gas, and water sectors. Other responsibilities of EWURA include licensing, standards, tariff review, performance monitoring and enforcement of compliance with the law and its standards were also granted to the EWURA Act. The scope and relations between the MEM, regulator and operators of the sector are determined by legislation. In addition to that EWURA has the duty to improve the welfare of Tanzania society by promoting electrification [10].

The Rural Energy Agency (REA): is also self-governing under the Ministry of Energy and Minerals, the primary responsibility of REA is to promote, stimulate, facilitate, and improve modern energy access in rural areas to support economic and social development. The second task is to promote rational and efficient production and use of energy in order to facilitate the identification and development of improved energy projects as well as activities in rural areas. The third responsibility is to finance eligible rural energy projects through the Renewable Energy Fund (REF); the fourth is to prepare and review application procedures, guidelines, selection criteria, standards, terms and conditions for the allocation of grants; the last two responsibilities are to build capacity, provide technical assistance to project developers and rural communities; and facilitate the preparation of bid documents for rural energy project [11].

Tanzania Petroleum Development Corporation (TPDC): is a national Institution established in 1969 which the Ministry of Energy and Minerals implements petroleum exploration and development policies. TPDC's mandate is to undertake all activities that involve exploration and production of oil and gas in the country [12]

Tanzania Geothermal Development Company Limited (TGDCL): is the national institution responsible for geothermal exploration, development and all activities regarding investments in geothermal [13].

2.2.3 Potential and consumption of energy resources in Tanzania

Hydropower

Studies advocate that Tanzania's topography is most suitable for medium, to high head pico and micro hydro run of river schemes. Tanzania's overall technical hydropower potential has been estimated at 4.7GW in total, only 12% of which current being exploited [5]. Although this varies according to that the country is located in the great lakes region to be precise Lake Victoria, Tanganyika, Nyasa, Rukwa, Eyasi, Natroni and Manyara. Besides, Tanzania has rivers and basins such as rivers Rufiji (Rufiji basin); Kagera (Lake Victoria basin); Malagarasi (Lake Tanganyika basin); Ruvuma (Ruvuma and Southern Coast basin); Mara (Lake Victoria basin); Pangani (Pangani basin); Ruaha (Rufiji basin) and Wami (Wami Ruvu basin) [14][15].

Natural Gas

The exploration of oil and gas in the United Republic of Tanzania is dated since 1974 in Songo- Songo Island. Due to financial problem, that time the field was not developed. After six years only, TPDC discovered oil and gas in the South-east Tanzania place called Mnazi Bay. In 2010, discoveries followed in the Mtwara region located in the southern part of Tanzania. The actual total natural gas proven in the entire country is estimated to be 46.5 trillion cubic feet (TCF) (December, 2013), equivalent to more than nine billion barrels oil. But Tanzania is still depending on external petroleum source because the oil is not yet discovered. Only 4 TCF have been exploited in Songo-Songo and Mnazi Bay. The later is used to supply gas at different gas-fired power plants namely Kinyezi I, II, III and IV with capacity of 150MW, 240MW, 600MW and 500MW respectively and Kilwa Energy of 210MW. In addition to that, currently Tanzania aims to build a new plant on the border of Dar es Salaam in Mkuranga [5][14][15].

Petroleum

Presently, petroleum resources in Tanzania are not yet commercially proven and developed. This leads the entire country to depend on imported fuel products, in the refined form and some crude oil. Total imported petroleum products account 30% of the total import bill. Only 40% is used locally whereas 60% is transported to neighbouring countries like Burundi, Democratic Republic of Congo (DRC), Malawi and Rwanda. While Zambia get the crude oil via pipeline that pass at Dar-es-Salaam port to directly Ndola [5][14][15].

Geothermal

Studies (geological, geochemical and geophysical) suggest that Tanzania has geothermal potential in most parts of the East Rift Valley system. These sites are: Songwe (Mbeya), Luhoi (Rufiji), Manyara, Lake Natroni,and Kisaki (Morogoro). Geothermal potential is estimated to generate about 650MW of electricity but up to now, approximately 140 to 380MW have been exploited [5][14][15].

Coal

According to pre-assessment report of the Tanzania energy sector under the Principles of the International Energy Charter and the Energy Charter treaty of 2015, the estimated potential of coal is about 1.2billion tonnes and only 30% of reserve has been proven which is equivalent to 304million tonnes. While the annual report of Power Africa, 2014 states 1.9billion tonnes with 25% have proven reserves. The coal sites include Mchuchuma/Katewaka, Kiwira, Rukwa and Ngaka plus about 220 million tonnes recoverable around Lake Victoria. Up to present, there is no power generated from coal, but the government is planning to use these resources for power generation [5][14].

Wind

Assessment have been identified the energy wind potentials in the highland plateau and regions passed by the rift valley of Tanzania. Makambako (Iringa) and Kititimo (Singida) have promising wind speed of 8.9m/s and 9.9m/s respectively, at the height of 30m. Further assessments conducted by energy authority in charge (MEM, TANESCO and REA) are continuing in the region of Mkumbara (Tanga), Karatu (Manyara), Gomvu (Dar es Salaam), Litembe (Mtwara), Makambako (Iringa), Mgagao (Kilimanjalo), Kititimo (Singida), Mafia Island (coastal region) and Usevya (Mpanda) [5][14][15]. Up to 2015, Negotiations of developing wind energy were on going, companies interested in were Geo-Wind Tanzania Ltd, Wind East Africa in Singida and in Sino, Tan Renewable Energy Limited in the Makambako, Njombe region and Wind Energy Tanzania Ltd. But Power Pool Africa was step up ahead to get a power purchase agreement of generating 100MW of electricity from wind farm in the Kititmo area in the Singida region [5][14][15].

Solar

Making reference to its geographical situation, Tanzania has a good solar irradiation ranging between 4 to 7kWh per square meter per day (4-7kWh/m^2/day) according to online solar radiation map. The energy potential varies between 2,800 to 3,500hours per sunshine per year and solar energy resources is very remarkable in the central parts of the country, which makes it suitable and reliable solution to electricity demand for both off-grid and grid-connections [15].

Off- grid photovoltaic

Currently, installed capacity of solar photovoltaic electricity is at the extent of about 6MW (megawatt peak) off-grids countrywide. Generated electricity is for various applications in hospitals, health centers, schools, public offices, private enterprises and commercial houses, as well as households and public lighting of some roads. Besides, there are mechanisms aiming to spread and reinforce the sustainability of solar technologies especially in off-grid regions such as Sustainable Solar Market Package (SSMP) and Lighting Rural Tanzania, both solar PV programs are supported by the Tanzanian government through Rural Energy Agency (REA) and various donors [15].

Grid-Connected Solar Photovoltaic

To date, Tanzania has one solar power plant in the central part; it generates about 1,800MWh per year and takes one hectare of land. Power System Master Plan (PSMP) predicts that electricity share from solar energy, mainly from isolated grid tie will be at 20% of total generation (800MW of 4,700MW peak demand) in 2025. But in short term plan, the government of Tanzania aims to generate 120MW of Solar by 2018. The market is open for investing in 50 to 100MW of solar PV, but only NextGen Solawazi has signed an agreement with the government to supply 2MW of electricity from photovoltaic to an isolated grid, and TANESCO aspires to generate 1MW isolated grid tied PV project [15].

Solar Thermal

Tanzania has undoubtedly solar thermal energy potential widely used in agriculture domain for drying crops, wood, cereals, coffee, pyrethrum, etc. Solar thermal energy is also used to heat water by use of solar water heaters especially in households and institutions such as hotels, hospitals, health centers and dispensaries. Still the use of solar thermal and warm water heated by solar is at low level due to constraints such as lack of awareness, financing challenges, and mindset (low priority given to the investment) [5][15].

Biomass

Biomass is occupied the biggest share of the primary energy usage in Tanzania. Biomass energy resource is used in variety of forms which can be classified into two categories: woody biomass and agro-forestry waste (crop wastes, animal manure, and forestry processing waste). These energy raw materials can be burned directly or first converted into solid (Charcoal), liquid (ethanol) and gaseous fuels (biogas). However, in Tanzania biomass is produced in traditional and unsustainable ways. Around one million populations are involved in charcoal preparation and supply. Due to lack of regulations and coordination, huge biomass energy resource quantity is from deforestation [5][15].

According to World Bank report, 2010 on charcoal use in Tanzania states that a) some 100,000 to 125,000hectares of annual forest loss is attributed to unsustainable charcoal production and b) Tanzanian government loses about US$ 100million in annual revenue. Currently biomass is used for electricity generation, first 18MW for grid and about 58MW from agro-industry generation. The potential for modern biomass use is enormous, like 1.5Milliontones of sugar bagasse produced per year

(MTPY), sisal (0.2MTPY), coffee husk (0.1MTPY), rice husk (0.2MTPY), municipal solid waste (4.7MTPY) and forest residue (1.1MTPY) as well as fuel wood from fast-growing tree plantation [5][15].

Uranium

Tanzania's uranium potential started in the 1970s, and the exploration ended in 2005 bring to light the exploitation deposits in Namtumbo, Ruhuhu near Lake Nyasa, (Ruvuma) and Manyoni (Singida), Handa and Bahi (Dodoma). Despite uranium energy potential, Tanzania has not yet nuclear power but has formed a task force in charge to develop nuclear technology to enhance power capacity [5][15].

2.3 Energy use in health facilities

Health facilities connected to electricity grid most of the time rely on grid power as a primary source. Since health facilities need to offer emergency care such as childbirth, surgical services, and patient security; having a backup system is a mandatory. When there is problem of power outage caused by peak demand or failures in supply, most of the cases these facilities rely on expensive backup generators or remain without power if the generator is not ready. In off grid facilities, standalone diesel powered generators have been taken as the primary solution with backup of kerosene lamps, candles or flashlights. The high cost presented by a diesel generator is due to fuel cost, its transport, storage and lack of local maintenance label. However, as the cost of renewable energy falls, the health facilities are using renewable energies either as primary or backup energy source; this applies in most cases to solar PV systems.

2.3.1 Energy supply

In health facilities, primary electrical power supply can be realized through different options. Power supply options include autonomous PV systems, autonomous diesel generators, hybrid system (for instance a combination of diesel, solar and grid, or combination of solar, grid and other renewable like wind), and power grid supply alone [16]. Balancing energy demand and supply is always challenging task. The challenges can be worse in the isolated facilities where access to adequate supply infrastructure is a limiting factor.

In some occasion the prioritization of supplying power to different medical and non-medical equipments can be considered as the solution to balance demand and supply. Consequently, critical loads are defined as the electrical equipments that need a continuous power supply while non-critical loads are all equipments that do not need a continuous power supply during power outage. Both critical and non-critical loads are electrically supplied by the same power source. However, in some occasion critical and non-critical load are separated in order to provide a dedicated power supply to the critical loads by using back up means such as diesel generator, UPS and or solar PV battery based system [17]. The energy demand requirements in health facilities and health facilities' location characteristics play an important role to determine a recommended economical viable power supply option. The supply options will be influenced by many factors, but the important ones include local available energy technologies, capital and operation costs of the energy system, availability of electricity grid and energy demand requirements.

For small and off grid health facilities where there is enough sunshine and energy demand requirement is less than 5kWh/day, autonomous PV systems with no diesel are recommended. However, when the energy demand exceed 5kWh/day, hybridized systems are advantageous [16].

2.3.2 Energy demand

In the planning phase of energy demand of health facilities the most important task is balancing the energy supply and energy demand. In rural areas the health facilities daily energy demand varies through the year depending to different facts such as health and non-health services require power usage. Therefore, a detailed inventory of all devices and their energy consumption is essential. The inventory contains a listing of devices and their quantity, operational power of device and daily working hour of device. Operational power and daily working hour of equipment are useful information in determining daily energy demand.

Accurate information about the daily energy demand involves measurement of power consumption of equipment for a time period, or use of other sophisticated method like controlling duty cycle of equipment (for compressor) [16]. A part from measurement, power consumption of equipment can also be obtained by reading the name plate's electrical parameter or nominal power [17]. The daily running time of equipment is obtained from the user information or investigating the function and usage of the equipment. The equipment's energy is then calculated by multiplying the power and daily running time of the equipment. Before and after determining daily energy demand of a facility; energy-efficient devices are highly recommended in order to balance energy demand and available energy supply.

In addition to electricity needs in facilities, health facilities also need thermal energy for cooking and water heating, laundry services, sterilization, space heating and incineration of medical waste. Such energy demand is significant in large health facilities such that it may be met by combining more than one solution. Some used solutions include; strong grid electricity supply, cogeneration of heat and power (CHP) systems, combustion of fossil fuel, solar PV and solar thermal [14].

2.3.3 Energy system at Kolandoto hospital

The main source of energy at kolandoto hospital is the electricity from national grid which drives most of all medical and non-medical electrical devices. According to the field study assessment, grid power behaviour is not only dominated by high frequency of unpredicted cut offs, averaged at 2hours every day based on statistical approach of diesel generator operation hours collected in the log book. But also, the electricity from national power has the big challenge of unstable power supply.

Apart from grid power, the other source of energy at hospital, is oil (diesel) based generator that supply electricity during grid outage. Its rating is 45kVA three phases. Compared to other generators, that run automatically during power cut of, this does not have the automation part, the electrical technician of the hospital has the responsibility to turn on and off manually, which usually makes an interval of period (blackout) not less than 5minutes or above to re-establish the electricity. The mentioned periods without electricity are the critical problem to inpatients lives as well as affect surgery and laboratory machine operation performance.

However another drawback connected to manually operation of the generator, is the over consumption of fuel during the time grid power is re-established and before the time a person in charge recognizes restoration of the electricity and turns off generator. Above to this challenges, generator capacity is less than the whole hospital demand load, for example bad working conditions of the generator was noted when some devices like laundry machines, water pump, sterilisation and boiler machines as well as other similar high loads devices were connected at the same time to the diesel generator which consequently affected health services of the hospital.

Biomass, particularly firewood is an additional form of energy used by the hospital to burn solid waste collected from different hospital activities. Biomass in form of charcoals is also used to cook foods at the hospital restaurant (the restaurant serves hospital staffs and students nearby, approximately 100 persons per day).

2.3.4 Health facilities types and associated main loads

Health facilities are classified into three to five basic levels of health facility services according to global survey of medical device availability by country conducted by World Health Organisation in 2010 [2]. But categories varies with countries' health systems, policies, accessibility to the infrastructure (for example energy source) as well as socio-economic and environment development orientation of each country. Most commonly health facilities types including:

Health clinics/health posts provides basic health services to population surrounded the post, they offer treatments for the most predominant diseases for example malaria, HIV/AIDS and TB like in Sub-Saharan Africa. Same clinics have responsibilities to take care of children's health in accordance to combat child mortality, sensitize companion particularly mothers measures regarding reproduction and improvement of maternal health [16][2].

District health centers give a wide range of services to large populations compared to health clinic, but also they are district health are larger, contain more patient bed and more advanced services such as complex obstetric procedures, injury response and diagnosis and treatment of serious infections and fevers [16][2].

District, provincial and regional hospitals provide health services to mass population with more diverse and advanced medical treatment like surgical, treatment of non-communicable disease [16][2].

Above the classification of health center according to available facilities, they can also be categorized based on the energy daily load demand. Small health centers that require average daily energy consumption which not exceed 10kWh/day, Medium health centers utilize daily energy consumption which varies between 10 up to 20kWh/day and large size health centers which consume above 20kWh of energy per day [16].

The main loads associated to each class include:

- ***Health clinics/health posts (small)***: Communication system,lighting and refrigerator.
- ***District health centres (medium)***: Communication system, computer, lighting, refrigerator, TV, microscope, water pump, fan, centrifuge machine, sterilizer, water treatment, water supply and staff amenities.
- ***District, provincial and regional hospitals (large)***: Communication system, computer, lighting, refrigerator, TV, microscope, water pump, fan, centrifuge machine, sterilizer, water treatment, water supply, X-rays, operational theatre devices, spectrophotometer, and staff amenities.

2.4 Power systems in health facilities in east Africa region

Generally access to electricity in east Africa region is still low despite differences levels between facilities and countries. For instance, according to [2]; only 50% of health facilities investigated in Tanzania had electricity while only 19% of them had a reliable electricity as shown in table 2.1. More again, in 2006, 2% of hospitals in Tanzania had no electricity while 6% had only diesel generator [2]. In the same year, 92% of hospitals was connected to grid or a combination of grid and others power sources with 23% of reliability. As it is shown in table 2.1, the highest electricity reliability in region is found in Rwanda which is 52%. These statistics explain how the journey to raise electricity access and reliability in health facilities is still far in east Africa. The most useful technologies to provide both power supply and reliability in health facilities of east Africa region include electric power grid, diesel generator, solar and UPS system. The subsection gives an overview of each technology, its use and challenges.

Table 2.1: Electricity access for health facilities in East Africa Community [2]

Country, year (No. of Facilities)	No Electricity [%]	Generator Only [%]	Central, Solar, or Other supply [%]	Reliable Electricity [%]
Tanzania, 2006 (N= 611)				
All Facilities	50	2	47	19
Hospital	2	6	92	23
Other facilities	52	2	45	19
Uganda, 2007 (N= 491)				
All Facilities	58	1	41	15
Hospital	1	5	94	16
Other facilities	60	1	38	15
Rwanda,2007 (N= 538)				
All Facilities	18	6	76	41
Hospital	2	10	78	52
Other facilities	19	5	75	40
Kenya, 2010 (N= 695)				
All Facilities	26	2	72	15
Hospital	2	2	96	24
Other facilities	28	2	70	14

Electric power grid

Electric power grid is an electrical power system that ties power producers and power consumers through transmission or distribution power lines. As shown in table 2.1 a considerable number of health facilities are connected to the grid in all countries which is reasonable as the investment cost is not a concern to health facilities. However, the health facilities that have power grid in developing countries are still concerned by its stability. To ensure the stability of power from grid; the demand is always matched with supply. But, this is still a challenging task to power system planners and operators in many developing countries because planning, operations and maintenance of power system become sophisticated in interconnected grid than in local and isolated grid. However, either in interconnected or isolated grid; the reliability of power grid is supported by modern power infrastructure and variability in power production systems. Thus, improvement in grid reliability implies high investment in generation, transmission and distribution. This is the reason; poor infrastructure and lack of sufficient power sources in east Africa countries enlarge insecurity in their electric power systems.

Diesel generator

Diesel generator uses internal combustion engine to generate electrical power. The combustion engine of a diesel generator uses fuel compression ignition principal that transfer mechanical energy to the generator shaft which in return generates electricity. Diesel generator is used to produce electricity in places where power is not reliable or non-existent. Diesel generator has become competitive among power backup systems because of it is robustness and efficient. This is why diesel generator is in use across health facilities, hotels, business centres, data centres, telecommunication, mining and other places where uninterruptable power supply is required. However, as the global fuel price is becoming volatile while use of alternative renewable technologies are growing; many countries and organizations are considering renewables such as solar and wind to replace or supplement diesel generator.

Solar PV

Solar PV uses sunlight to generate electricity for supplying electrical load. The technology of solar PV has become more affordable and efficient in recent decade. According to [18], for all public health investigated; 146facilities were using solar PV as primary power supply while 116facilities were using diesel generator. Moreover, the reliability offered by solar PVs was estimated to be 81% while the reliability offered by diesel generators was 52% [18]. This may result from the promotion of onsite energy solutions measures, robustness and diversified applications of solar PV technology. For instance solar PV can be used in all health facilities' electricity needs such as cooling, refrigeration, lighting, equipment sterilization, water pumping and laboratory operations. However, due to intermittence nature of solar PV; it is more convenient to mix solar PV with other power sources to mitigate the consequences associated to the intermittence of solar PV. According to [18] a well maintained hybrid solar power system can attain fuel saving of 75-80% with acceptable reliability of power supply .

UPS based system

A UPS (Uninterruptible Power Supply) is an electric power device used to provide power during emergency to specific loads at customer level when the main power supply fails. A UPS is a series connected device that protects the load from interruption and voltage dip. During main power failure, the UPS supplies the load with stored energy for a short time. The storage devices in UPS are usually batteries and super-capacitors. For this reason, UPS is made of by a rectifier, an inverter and storage unit. The AC input power from the main is rectified into DC power to charge storage power banks. The DC from storage bank is converted into AC at the output to supply the load. Due to this structure, high quality UPS provide pure sine wave AC power to the connected load. Thus UPS is a good device to mitigate interruption and power quality phenomenon at customer level. However, protection of UPS is complicated because UPS is a series device which is also a limit to its use at high power demand. On the other hand the UPS is an expensive device with a competitive application in computer servers, hospital services, bank services and other sensitive services like telecommunication and data centres in many countries.

2.5 Environment and economy of energy system in health facilities

Generally, energy system of health facilities worldwide is grid-based power supply and/or on-site heat and/or power production. The on-site energy production depends to the capacity, size and services of the facility and it is mainly fuel generator power [18].

In off grid areas, portable diesel generators have been used as the major source of power while in large clinics or hospitals, these are helped by second fuel-powered generator; small health centres utilize flashlight and kerosene lamps.

Undoubtedly, power source quality is directly connected to health services performance at the hospitals such as childbirths, out-patient clinic handling, emergencies, day surgeries, vaccine storage, laboratories, etc [18]. In many health facilities of developed countries grid power remains mode of energy supply, and one reason health services of those countries are still ranked at high quality is due to stable and continuous energy supply whereas, developing countries are still struggling with daily grid supply interruption and backup power system challenges.

The later which is usually diesel generators, currently is no longer considered as an adequate power backup solution because of its drawbacks; first, fuel has been increasingly expensive which negatively affect total health service costs. And second, power back up of fossil fuel based are considerably increasing emissions to local population and globally as well.

However, hospitals of developing countries suffering stated challenges are investing more thoughts and money in on-site clean power generators in order to (i) alleviate the persisting electricity shortage and cut off, (ii) reduce the electricity bill expenses and (iii) reduce oil fuel dependence which will reduce emission as well.

3

Methods

During this thesis various methodologies have been adopted to understand and to get tangible data which are used in the course of the research. What have been done so far include; documentation, energy measurement, participatory observation, participatory workshop, interview, calculations,and modelling.

3.1 Literature review

Through literature review the renewable energy sources available in Tanzania which can be used to alleviate the gap between the energy demand and energy supply in health facilities, residential, schools and community commercial areas are documented. The potential shares of each source have been represented. There was also a need of making an inventory of all electrical devices at Kolandoto hospital (hospital taken as a case study in this research) in order to estimate total energy consumption. The inventory of energy system has been investigated not only based on literature review but also with use of other methods mentioned above.

3.2 Energy measurement and participatory observation

In order to know the energy consumption of Kolandoto hospital and to evaluate the feasible solutions (local) that can support the energy demand in lighting, heating, cooling and driving medical and other equipments; measurement of power consumption of equipments was conducted. The measurement tool was PM-498 a plug-in energy measuring tool that measure energy an electrical device connected to it uses.

Table 3.1: Features of PM-498 energy meter

	Capacity	Output values	Used values
PM-498 energy meter	-	Voltage	
	-	Mean current	
	-	Maximum current	
	-	Mean power	✓
	3.5kW	Maximum power	✓
	-	Running time	
	-	Energy	
	-	Cost	

Due to characteristics of PM-498 energy meter and those of equipments to be measured, during the course of measuring phase this agreement has been adopted: Before measuring any equipment it was necessary to check its name plate electrical ratings to be sure if it is within the capacity range of PM-498 energy meter. Only plug-in devices with power rating less than 3.5kW have been measured. Since the majority of devices found at Kolandoto hospital their power ratings were small, it was requiring long running time to have energy value displayed by PM-498 energy meter; therefore a decision of reading maximum power and mean operation power values was taken. Reading only these values has saved the time of measuring several devices by using only two PM-498 energy meters.
The time taken to measure each device was between 5 and 20minutes. 5minutes has been used to equipments that present constant power consumption like microscope while 20minutes has been used to equipments that were presenting high variation in power consumption like fridge and air conditioners. However, two fridges and two air conditioners taken randomly have been measured in 24hours to assess the energy consumption of these devices which were presenting higher difference in readings taken in different time intervals. For 24hours measurement, the energy and running time were interesting as the idea was to see if measured energy value and calculated energy are different. The results from both methods have almost been the same.

3.3 Participatory workshops

Two workshops have been held in Kolandoto hospital in two different time intervals with different objectives. The first workshop was about inventory list of all equipments and inventory list of critical loads. The second workshop was about the energy management measures that can be in place to sensitize hospital staffs the use of electricity efficiently. During both workshops, participants were medical doctors and other hospital staffs that are heading different units and two engineers who were collecting data. Based on Kolandoto hospital electrical equipments survey conducted by [19]; participants of first workshop updated both critical loads list and less critical loads. They have made a consensus for what is critical load and in what circumstances it can be critical or not.

Critical load was defined by the workshop attendants as any load that needs a continuous power supply during the surgery operation and during emergency activities. This definition is based to frequent electrical power interruptions noticed at Kolandoto hospital. Due to those power interruptions, one hour has been taken as reasonable time for caring a patient or to be prepared for next procedures.

The following equipments have be selected as critical in one hour of operation time; Anesthesia machines, Suction machines, Operation lights, Lights in maternity ward, Electro surgery machines, Some normal lights in theaters, Microscope in laboratory, Baby warming machine, Oxygen machine and Microscope in eye theater.

3.4 Interview

There was a need of some value like running time of lights, number of medical devices, etc. The interview with responsible persons of equipment has provided valuable information. It was hard to know the running time of some equipments since no one had a clear understanding of what time equipment is working or not. It has been revealed also that there is no proper time of operation to some equipments depending on its usage and or case of patient requiring its usage. In this regard, during the interview at least three persons were interviewed and their information was collected to make a probable time which has been used in the calculation formula of energy consumption.

3.5 Calculation

Calculation has been carried out especially through solar PV system design where ratings of equipments are calculated based to common formulas found either in literatures or in manufacturers' brochures. The main data used in this context is electrical power and running time in order to evaluate energy consumption of equipment. The energy is calculated by multiplying the AC power by the running time of equipment. The AC power is from measured values or read on name plate of equipment while running time is from the interviews. Two different values from measured values were available, that is maximum power and operation power.

It has been seen that maximum power measured by PM-498 energy meter in some devices such as electro-surgery machine, suction machine, anaesthesia machine and old fridges were quite different to either rated power or operation power. This has raised confusion on what should be used in calculations of energy consumed by those equipments. After consulting literatures and analyzing the functionalities of such equipments; it has been noted that the operation power measured by PM-498 energy meter differs from name plate value due either to the oldness of equipment or to what function the equipment is performing. It must be remembered that some of these devices are made to deliver multiple functions while Kolandoto hospital uses like 30% of all functions. Therefore 20% of measured operation value has been added to lower values while nominal ratings has been taken to higher values during calculation of energy consumption. Here 20% stands for possible increment in power consumption while nominal rating stands for possible maximum power certified by device's manufacturer.

This is why two scenarios were been performed during design process of critical loads using solar PV system. The first scenario is based on measured power values (for equipments that do not present large differences to their ratings) and measured power values plus 20% of measured power values (for equipments that present smaller values than their ratings). The second scenario is based to nominal power ratings values. It was also important for this thesis to evaluate what would be required to have a solar PV system that can support the total energy of the hospital during power outage. Only the nominal power ratings values of equipments have been used here. The running time for critical loads is one hour while one hour and twenty four hours have been used to evaluate energy of all loads.

3.6 Modelling of power supply system

Design results obtained from sizing of solar PV system required to be integrated in the existing power system, were simulated and optimized through software named HOMER (Hybrid Optimization Model for Multiple Energy Resources) in order to be valid. Throughout simulations comparative costs, emissions, and technical aspects as basis of selection were carried out between possible power supply configurations. Two configurations were given high consideration in evaluation compared to the rests, which are baseline system composed by grid power plus diesel generator versus a concerned one comprises of a solar PV system with battery backup system coupled with grid power and diesel generator.

HOMER was chosen as outstanding software among other PV system designing software such as SAM (System Advisor Model), RETScreen, PVsol, and PVsystem. Three main features that HOMER software can perform include; *through simulation it presents different design options (configurations) including hybrid systems, through optimization a design based on net present value is obtained and through a sensitivity analysis a financial analysis is carried out.* During simulation process, HOMER software models the performance of various hybrid systems and determines their technical feasibility accompanied by their life cycle cost. While in optimization process, HOMER simulates various system design options (configurations) in order to come with the optimal system configurations which satisfy the technical constraints at lowest total net present cost. During sensitivity analysis, HOMER conducts multiple optimizations under a range of input sensitivity parameter of fluctuating parameters.

Inputs used during modelling were from the design calculations such as equipment specifications, capacity and quantity. However, other inputs like required load were taken from the inventory analysis. Costs of key components such as hardware, installation, accessories and labor as well as fuel (diesel) were considered based on local prices, meaning prices information were collected during field study but other costs like interest rate for capital investment were also documented. Important inputs parameters include:

Load profile

To design the power system, optimization of power demand and supply sides were carried out; this means the loads shifting of the energy demand and energy supply for instance grid load, solar PV system and its components were modified to match energy balance.

The simulated system demand load was constantly considered at 8.2kW per hour along the day, which embraces the operation power demand for all critical equipments at Kolandoto hospital according to inventory study (see appendix A). To simplify the analysis, assumption was initially made to this load and entered as hourly steady load into software. In general the load cannot remain constant in real life; due to that, random variability of demand load was adopted by considering possible load changes for different days of the week and possible changes within one hour, considered as time-step in this study. Because the hospital services includes emergencies activities are equally distributed across seven days per week during the year, 10% was considered as possible load variation between day to day, and on the other hand, 40% was randomly considered as possible variation within time-step (on hour) based on that some equipments at starting operation point consume high energy than normal operating power or can also be explained by the probability of running loads at the same time, which can be less as well because of all medical equipments can not functioned at the same time.

Furthermore, on the supply side, 3.2kW as capacity of solar PV from design results was entered in the software, 36kW as capacity of the existing diesel generator at hospital was considered as well, and 17kW was seen as less required load from grid. Afterward, demand load profile was generated and load variation used was studied on how it affects other parameters such as peak load, economic and emissions parameters.

Economic parameters

The economic evaluation of modelled systems was carried out, parameters such as levelised cost of the electricity (LCOE), net present cost and life cost analysis, initial cost and payback period of each possible configurations were displayed out. However the report is delimited to only levelised cost of electricity and net present cost in order to select less affordable power system.

In the software, the levelized cost of energy (LCOE) is defined as the average cost per kWh of useful electrical energy produced by the system, and is calculated by dividing the annualized cost of produced electricity by the useful energy production as indicated by the equation 3.1.

$$LCOE = \frac{C_{ann,tot}}{E_{prim,AC} + E_{prim,DC} + E_{grid,sales}} \tag{3.1}$$

Where, $C_{ann,tot}$ stands for total annualized cost (\$/yr), $E_{prim,AC}$ is AC primary load served (kWh/yr), $E_{prim,DC}$ is DC primary load served (kWh/yr) and $E_{grid,sales}$ is total grid sales (kWh/yr). The total annual cost is the sum of the annualized costs of each system component plus the other annualized costs.

The total net present cost (TNPC) which is defined as the present value of all the costs that incurs over the lifetime, minus the present value of all the revenue that earns over its lifetime duration. The costs considered include, initial capital costs, replacement costs, operation and maintenance (O&M) costs, fuel costs, emission penalties, and the cost of buying power from the grid. Therefore TNPC stands as major economic parameter because all systems simulated are ranked according to it. Its mathematical formula is:

$$C_{TNPC} = \frac{C_{ann,tot}}{CRF_{i,proj}} \tag{3.2}$$

Where, C_{ann}, tot is the total annual cost (\$/yr), i is the interest rate (%), R_{proj} present the project time (N), and CRF stands for capital recovery factor and calculated as:

$$CRF_{i,N} = \frac{i(1+i)^N}{i(1+i)^N - 1} \tag{3.3}$$

Concerning the cost inputs used, for solar PV system investment cost includes balance of system parts, like cabling cost, installations/labor and accessories cost were estimated as US $ 1.4/WP, the cost of battery of 12V, 245Ah was considered as US $ 588/unit based on local market price. Inverter of 15kW capacity its cost was estimated at US $ 501/kW based on online and documented prices. Moreover the investment cost of a diesel generator of 36kW capacity was set at US $ 1000/kW based on documentation. While fuel (diesel) cost US $ 1 per liter was taken from current prices of the East Africa region market particularly Tanzania. The cost of buying power from the grid is US $ 0.1/kWh. Regarding the discount rate for capital investment and the expected inflation rate were considered as 7% and 4.89 respectively as the average values. Because both rates can widely vary in Tanzania, the fluctuations of discount rate and expected inflation rate were handled by considering a range of 5 to 14% for discount rate and 0 to 6.1 for inflation rate during sensitivity analysis.

Emission parameters

Emission menu in the software allow specifying a cost penalty associated with a pollutant, or limiting on the emissions of a pollutant. During this study the emissions parameters looked upon were, dioxide carbon (CO_2), monoxide carbon (CO), and dioxide sulphur (SO_2) and mono & dioxide nitrogen (NO_X), In addition to that, the amount of unburned hydrocarbon (UHC) and particulate matters (PM) from burning diesel fuel were considered. All emission quantities of possible configurations are estimated in kilograms per unit of time [kg/year].

Concerning emission inputs entered in the software for example the grid emission factor (GEF) for Tanzania was documented and found as 586gCO_2/kWh according to Clean Development Mechanism (CDM) of Tanzania report, 2010. And for the diesel fuel contains 2663.5grams of carbon per liter. Inputs of insignificant remaining emissions used like unburned hydrocarbon, particulate matter, sulfur dioxide, nitrogen oxides, were collected from Homer library. In this study, emissions of these pollutants are resulted from the production of electricity by the diesel generator and consumption of grid electricity.

Besides mentioned inputs, there are other standard inputs like efficiencies of different equipments and solar irradiance of the site studied. All of those inputs were collected from software library where solar irradiance is correlated as the data of the fig 4.1. Finally, after multiple simulations executed through adjustments of inputs, optimized results were obtained. Four possible power supply configurations with their electrical loads, required costs, and quantity of units and emissions of each were put on view. Beyond combined results, power output behaviour, costs and emissions of each configuration were examined separately.

4

Theory

4.1 Solar PV system

Solar photovoltaic (PV) system or solar power system is one of renewable energy system which uses PV cells to convert sunlight into electricity. PV cells interconnected together form a PV module. The electricity generated can be directly used or stored for later use. The solar PV shouldn't be confused with other solar technologies such as concentrated solar power (CSP); system that use mirror or lenses to concentrate sunlight from a wide area to a small area) and solar thermal (heating and cooling) [20].

The electricity from PV module can supply appliances connected directly to it or through a set of power converter devices. In some conditions, it can also feed power back into the grid line through a grid tied inverter when solar PV system is interconnected with power from the utility. Solar PV can also be integrated with one or more other electricity generating source like other renewable energy sources. Solar PV system is very reliable and clean source of electricity that can suit in a wide range of electricity applications. However, each application in order to be effective; there is a need to assess the potential of solar photovoltaic at given site, components of solar PV system required and types of configuration to perform the intended production services.

4.2 Assessing site for solar PV system

Evaluation of solar photovoltaic system site consists of gathering necessary information and study the practicality of the site to enhance best performance of the system. Focuses of the assessment includes:

Mounting location: With an economical, safety precaution and good performance point of view, PV modules are usually mounted on dead zones, such as roofs. But if surface area of the roof is not adequate, solar panels can be poled-mounted, ground mounted or wall mounted [20].

Shading: studies recommend avoiding shadows (the one which can produced by nearby house, single branch of tree, chimney, etc.) on PV modules because they are substantially affect the power output of a solar module. A well designed PV system needs clear and unobstructed access to the sun's radiation approximately 6 hours (from 9 a.m. up to 3 p.m.) [20].

Orientation: In the southern latitude, by the conventional wisdom solar PV modules are oriented towards north pole while in the northern latitude are oriented towards southern pole. in general, studies suggest that the optimum orientation of the PV modules should be towards the equator [21].

Tilt angle: is an important parameter in the optimum utilization of solar panels often symbolised by (β), is defined as the angle between the plane of the collector surface and the horizontal. Consequently, the magnitude of it affects the efficiency of solar panels. The optimal tilt angle of a solar collector depends to geographic latitude, local climate condition and period of its use [22].

Regarding the magnitude of the angle, some literature simplify the task, for example Garg in [23] and Lunde in [24] suggest that optimum tilt angle (β_{opt}) is equivalent to plus or minus fifteen degree only. Whereas Duffie and Beckman say that the tilt angle is equal to local latitude plus or minus fifteen degree which has been emphasised by Heywood also. Where minus and plus degree is used during summer and winter time respectively [21].The table below summarises the impact on average solar irradiation can be collected in the region of Shinyanga, Tanzania at different tilt angles [3].

Table 4.1: Monthly average radiation incident at Shinyanga-Tanzania [3]

Monthly Averaged Radiation Incident On An Equator-Pointed Tilted Surface (kWh/m²/day)													
Latitude -3.549 Longitude 33.559	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Tilt 0	5.51	5.91	5.93	5.80	5.68	5.92	6.07	6.30	6.36	6.08	5.58	5.43	5.88
Tilt 3	5.56	5.94	5.93	5.85	5.79	6.08	6.22	6.40	6.38	6.10	5.63	5.49	5.95
Tilt 18	5.68	5.93	5.73	5.94	6.15	6.65	6.73	6.65	6.28	6.02	5.71	5.64	6.09
Tilt 90	2.78	2.39	1.70	2.66	3.57	4.33	4.17	3.29	2.08	2.17	2.68	2.88	2.90
OPT(optimized)	5.68	5.97	5.93	5.95	6.21	6.85	6.88	6.66	6.39	6.11	5.72	5.64	6.17

Required area: Space to accommodate solar modules is also important factor, in some region particularly urban areas, space are increasingly expensive day after day which can affect the total cost of the system, but this for the case of poled-mounted and ground mounted solar system. Regarding this issues, researches propose solar modules for residential and small commercial purposes to occupy dead areas for example roofs of houses, supermarket, parking, etc [20].

Roof type: Among all types of roofs, for PV modules roof-mounted system of course, the one with the composition of shingles are the easiest to work with while slate and tile are the most difficult which require additional supports to fix the system. It is recommended to work on the roofs which not require replacement under 5years just to avoid dismantling and re-installation cost [20]. For Building Integrated Photovoltaic modules (BIPV), which are nowadays promising to be largely expanded even if its cost is still very high, they can be incorporated into the roof itself and they might be put on during construction.

Among feasible energy sources at Kolandoto hospital region, which is not yet exploited but aimed in this feasibility study is the solar energy potential that can be used for power generation as well as thermal purposes. According to data from National Aeronautics and Space Administration (NASA) all three forms of solar power can be collected in the region, which include:

Direct Normal Irradiance (DNI), defined as the amount of solar radiation or power received per unit of area [W/m2] which is perpendicular to solar radiation that comes directly from sun's disc without any scattering by the atmosphere. Accurate DNI is mostly need during the use of concentrating collectors [25].

Diffuse Horizontal Irradiance (DHI) characterises solar power received per unit area on the horizontal surface, after its direction has been deviated by the atmosphere. Normally, DHI and DNI are more useful for daylight applications and cooling load calculations in energy efficient buildings [25].

Global Horizontal Irradiance (GHI), this solar power includes radiations received directly from solid angle of the sun's disc as well as diffuses sky radiation that has been scattered in traversing the atmosphere. The device used to measure it is called pyrometer on the surface [25].

Consequently, solar irradiance at Kolandoto area was collected on NASA surface meteorolgy and solar energy online webpage as illustrated by the figure 4.1

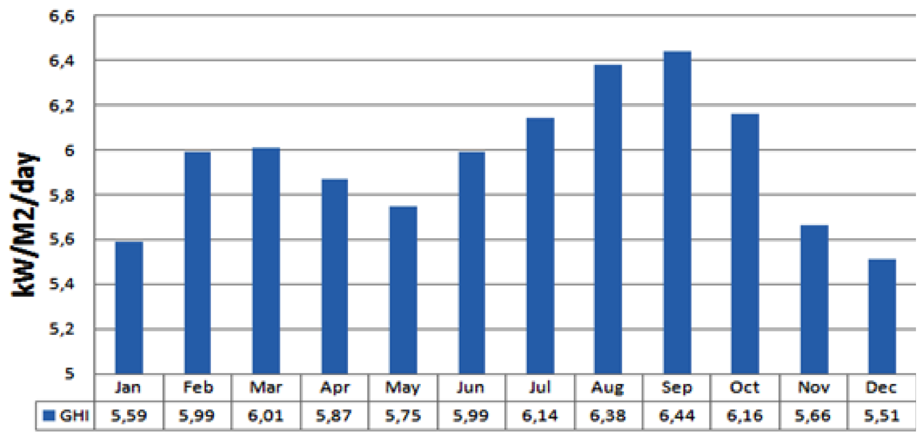

Figure 4.1: Solar irradience

4.3 Components of solar PV system

There are different components in solar PV system but the main components such as solar module, inverter, battery and charge controller are considered in the next subsection.

4.3.1 Solar modules

The basic element of solar PV system is a solar cell that converts sunlight into direct current (DC) electricity. PV module is formed by interconnecting several solar cells in series and/or in parallel to increase either voltage or current. The technologies of solar PV are classified in three categories [4]. The first category is wafer based crystalline silicon (c-Si), the second category is thin films (TF) and the third is emerging and novel PV technologies which includes concentrated PV, organic PV, advanced thin films and other novel concepts. However, the categories that are available on today's market are wafer based crystalline silicon (c-Si) and thin films (TF) [4].

The wafer based crystalline silicon stands for mono crystalline silicon (mono-c-Si), multi-crystalline silicon (multi-c-Si) and ribbon sheet grown silicon [4]. On the other side, thin films represent four basic variants; the first is amorphous silicon (a-Si), the second is micro morph silicon multi junctions (µc-Si), the third is Cadmium-Telluride (CdTe) and the fourth is copper indium selenide (CIS) [4]. According to IRENA report, in 2011 crystalline silicon (c-Si) took 89% of the global market share while the remaining 11% were taken by thin films technologies. The theoretical, market and laboratory record's efficiencies of the majority available cells are summarized in the table 4.2 where crystalline hold higher efficiency.

Table 4.2: Performance of PV cells technology [4]

	Cell efficiency (%)	Module efficiency (%)	Commercial and Lab record efficiency (%)	Area/kW (m^2/kW)	Life time (years)
c-Si					
Mono-c-Si	16-22	13-19	22 (24.7)	7	25(30)
Multi-c-Si	14-18	11-15	20.3	8	25(30)
TF					
a-Si	4-8	4-8	7.1 (10.4)	15	25
a-Si/µc-Si	7-9	7-9	10 (13.2)	12	25
CdTe	10-11	10-11	11.2 (16.5)	10	25
CI(G)S	7-12	7-12	12.1 (20.3)	10	25
Org.Dyes	2-4	2-4	4 (6-12)	10 (15)	Na
CPV	Na	20-25	>40	na	Na

A module is commonly a series or parallel connection of cells. Modules in series form a string and strings of modules in parallel form a PV array. The nominal voltage of a single module available on market is 12V, 24V and 48V. The performances of PV modules are compared based to the price per watt and efficiency (rated power per area). Efficiency is defined as wattage over the surface area, while price per watt is the price over rated output power [20]. The warrant of module depends to its technology (material used) and manufacturer's confidence. As it is shown in table 4.2, the PV module warrant is between 25 and 30 years.

Sizing PV module

The size of PV module depends on the energy consumption of equipment required, PV derating factor, weather conditions of a location and power conversion efficiency [26].

Weather conditions are presented by number of hours the sun shines at its peak which is derived from the daily average insolation with incident radiation of 1000W/m^2. The insolation value is used to evaluate the potential of solar in a location and it is found in meteorology institutes [3]. The yield of solar PV is influenced by different factors which are considered as derating factors. Derating factor varies from 30% to 90% [26] and it is calculated from the combination of shading factor, tilt and orientation factor, battery efficiency and PV module harvest efficiency. PV module harvest efficiency is based on module operating temperature, aging, dirty and loss in wiring [26]. Thus the derating factor ρ_{loss} is given by the expression:

$$\rho_{loss} = S_h \times T_{or} \times B_{att} \times M_{pv} \tag{4.1}$$

where:
S_h is a shading factor (80-100%);
T_{or} is tilt and orientation factor (90-100%);
B_{att} is battery efficiency (70-85%);
M_{pv} is PV module harvest efficiency (70-85%).

The shading factor S_h varies between 80 and 100%; this percentage represents the loss associated to the shading effect of solar PV modules. Tilt and orientation factor

T_{or} varies between 90 and 100%; it shows how orientation and tilt angle can affect the overall efficiency of solar PV system. Battery efficiency B_{att} varies between 70 and 85%; this depends to the fact that the stored energy in a battery is not equal the output energy due to internal loss in the battery components. Solar PV module harvest M_{PV} varies between 70 and 85%; these values depend to solar cell operating temperature, aging, dirty and loss in wiring [4].

Taking into account the AC energy consumption of equipment and the efficiency of inverter; the DC energy requirement to support AC energy demand is calculated as follow:

$$E_{prod} = \frac{E_{cons}}{\eta_{inv}} \tag{4.2}$$

Where:
E_{prod} is the DC energy;
E_{cons} is AC energy consumption;
η_{inv} is inverter efficiency.

The peak power produced by the solar PV array is given by the following expression:

$$P_{array} = \frac{E_{prod}}{I_r \times \rho_{loss}} \tag{4.3}$$

Where:
P_{array} is power from solar PV array;
ρ_{loss} is derating factor given by equation (4.1);
I_r is peak sun hours per day.

Finally, by inserting the equation (4.2) into (4.3); the peak power produced by the PV array is given by:

$$P_{array} = \frac{E_{cons}}{I_r \times \eta_{inv} \times \rho_{loss}} \tag{4.4}$$

The number of PV modules required to satisfy the power production P_{array} is found by considering the peak power rating of the chosen module. The actual number of PV modules required is usually updated during project implementation due to the factor that the number of PV in string and their nominal voltage are considered to determine the actual number of PV required to satisfy the inverter input voltage. The surface required is also an important parameter during solar PV sizing. Therefore, high efficient modules are encouraged in order to reduce the cost of placement of solar modules. The required area to accommodate solar PV modules is proportional to the total number of solar modules and the surface area of one module which is given by the manufacturer of the chosen PV module.

4.3.2 Inverter

Solar inverter is used to convert DC power from solar PV module or battery bank to AC power. Since the inverter is in series or in parallel with power source, it must be able to provide voltage and current of good profile to the load. The power quality and other features of an inverter depend on the technology and intended use. Some inverters have features that can fit well either in standalone configuration or grid connected system and or hybrid system. For example most grid connected inverters re outdoors whereas most standalone inverters are indoors, and some grid inverters are designed to work with batteries while others are designed to work without batteries [20].

The solar inverters reach peak efficiency (95-97%) when loaded between 30% and 50% of nominal power; at full load the efficiency reduces slightly to 92-88% [27]. Thus, under-sizing an inverter leads to operate it close to its full capacity, and therefore below the maximum efficiency [27]. Modern inverters without batteries have Maximum Power Point Tracking (MPPT) that automatically adjusts voltage of PV array in order to operate at maximum power point. For battery based system this feature is integrated into battery charge controllers.

When there is utility power outage, the battery based system's inverter can automatically shed non critical loads that are usually separated from critical loads that need continuous supply. For grid connected system, the inverter must be switched off during grid power outage to prevent the energizing of the dead line (safety precaution). The market of standalone inverters is the oldest with lower price to that of grid connected inverter. The warrant of inverter from manufacturers is 5 to 10 years.

Sizing of inverter

The size of inverter should comply with the AC power required by the total load. However, the input DC voltage window should also be in the range of solar PV array's nominal voltage which is usually 12,24 or 48V for battery based system and 235 to 600V for system without the battery. [20][28]. Inverter should be able to operate at maximum power point voltage and at open circuit voltage of PV array. The output power of the inverter is compared to AC power required by the load.

AC power output of standalone inverter is sized based to the load characteristics while AC power output of grid connected inverter is sized based to the power output of the solar PV array. This difference in sizing is possible because addition power required in grid connected system is directly drown from the grid. The start-up surge capacity and peak energy demand are a concern only for standalone inverter.

Since at start-up certain loads draw a higher current, the standalone inverter should be designed to withstand the overcurrent for a short time. The grid connected inverter can be oversized by 30% or undersized by 30% with regard to the size of the PV module while the standalone inverter is usually oversized by 35% with regard to the size of the AC load [4][28]. One can chose lower or higher value to the ones mentioned above, but he or she has to remember efficiency performance involved during oversizing and under-sizing a solar inverter.

4.3.3 Batteries

Batteries are devices that store electrical energy in form of charges. Batteries are made of multiple cells connected together with specific voltage (2V) depending on the technology used but independent of the cell's size. But, the cell's size depends to the amount of charge stored in a cell. The nominal voltages of batteries commonly available on market are 2V, 6V and 12V [20].[26]. Batteries are used in solar PV systems to store electrical energy collected from PV modules for later use, for instance during cloudy weather or in the night. However, batteries increase the complexity and cost of solar PV system. They also reduce the efficiency of PV system, therefore, the batteries type and operation conditions are of important consideration for optimal performance of a PV system.

The electrical energy stored in cell is proportional to the cell size and all energy stored cannot be delivered to the load due to what is called depth of discharge (DOD) of a battery. Depth of discharge describes the amount of energy that can be taken from the battery. Maximum DOD recommended in most batteries is 80% which means that only 80% of the battery capacity is useful [20]. The opposite term of DOD is state of charge (SOC) that reflects the amount of energy still stored in a battery. To maintain the batteries healthy for long time, SOC of batteries should not be close to zero.

Type of batteries commonly used in PV system include; lead acid batteries and alkaline batteries [20]. Lead acid (LA) batteries are the most common in solar PV systems. Generally lead acid batteries are divided in two classes; flooded lead acid batteries (liquid vented) and sealed batteries (Valve Regulated Lead Acid). Flooded lead acid (FLA) batteries are usually less expensive but require regular replenishing of water lost during charging process [20]. FLA batteries work well in standalone PV systems because are designed for more regular cycling. Sealed lead acid (VRLA) batteries are the most used in grid connected systems and do not require regular maintenance. Lead acid batteries can also be divided into two types; gel cell (GC) and absorbent glass mats (AGM) batteries [20]. GC batteries are very sensitive to overcharging caused by their freeze resistance whereas AGM batteries are maintenance free and suitable to grid connected systems where the batteries are almost kept at full state of charge.

Alkaline batteries (Nickel cadmium and Nickel iron) are recommended in cold environment (less than -46°C) and are expensive than lead acid batteries. Their high cost is due to their tolerance to low and high temperatures, they require low maintenance, and they withstand overcharging and deep discharges. Batteries for grid connected systems are sized to operate for a short time (hours) depending on the grid power outage time and level of reliability required. Battery banks for off grid systems are sized for relatively long time (days) depending on the cloudy weather, load operation time and level of reliability required. In the manufacturer catalogues; battery's voltage and capacity (Amp hour) are always provided. However, there are other parameters which are not provided by all manufacturers yet are important like discharge rate over a time period (10, 20, 24 hours) that depends to battery capacity's time usage. This rate is referred to as the C rate and is noted C/10, C/20 or C/24 [26].

Sizing battery capacity

The capacity of battery in solar PV system is directly proportional to the AC energy consumption during days of autonomy and inversely proportional to battery depth of discharge, nominal voltage, temperature coefficient, and inverter efficiency.

$$C = \frac{E_{cons} \times Aut}{\eta_{inv} \times Volt \times DOD \times T_{coeff}} \tag{4.5}$$

Where:
C is battery capacity;
E_{cons} is AC energy consumption of equipment;
Aut is days of autonomy;
η_{inv} is inverter efficiency;
$Volt$ is nominal voltage of battery;
DOD is depth of discharge;
T_{coeff} is battery temperature coefficient.

Battery temperature coefficient (T_{coeff}) indicates the efficiency of a battery at different operating temperatures conditions. This value is from manufacturer data sheet and varies with battery technology.
Number of battery is found by dividing the total battery capacity (C) by a capacity of one battery. The number of battery required is updated according to number of strings required to satisfy the inverter input voltage.

4.3.4 Charge controller

Solar charge controller regulates the voltage and current coming from the PV panels going to battery with the aim of keeping the battery from being overcharged or over discharged, thus, prolongs the battery lifespan. Two common types of charger controller based on their connection mode are shunt and series controllers. When batteries are almost full charged a shunt controller bypasses current through a power electronic device to dissipate excess power into heat. The application of shunt controller is for small systems. [20]. Series controllers' current flow is controlled by opening and closing of the circuit between the battery and the PV array. Series controllers are small in size, cheap and have been used in high load application than their counterpart. [20].

The charge controllers can also be classified based on the controlling algorithm which are Pulse Width Modulation (PWM) charge controllers and Maximum Power Point Tracking (MPPT) charge controllers. Pulse width modulation (PWM) charge controllers regulate charging event by adjusting the width and frequency of the full current pulses sent to the battery [29]. The advantage of PWM controllers is lowering the charging current. Maximum Power Point Tracking (MPPT) charge controllers' algorithm can operate a PV array at its MPP over a wide range of operating conditions and at a voltage much higher than the battery voltage [26]. This improvement in technology of controller increases power harvest by up to 30% and allows longer distances or smaller sizes of wires between the PV array and charge controller [4].

Sizing charge controller

The solar charge controller is typically rated against its amperage and voltage. According to standards, the size of solar charge controller is obtained from the short circuit current (I_{sc}) of the PV array. I_{sc} is overrated by 30% to get the amperage of the charge controller. Since most of the time charge controllers are used in off grid systems and hybrid systems with batteries; the charge controller's voltage must be set up such that it does not disturb the inverter. It is important to select controller that can deliver appropriate current for the types of batteries in place.[20].

4.4 Configuration of solar PV system

The different configurations of solar PV system adopted in this subsection are standalone system, grid connected system and hybrid system.

4.4.1 Stand-alone solar PV system

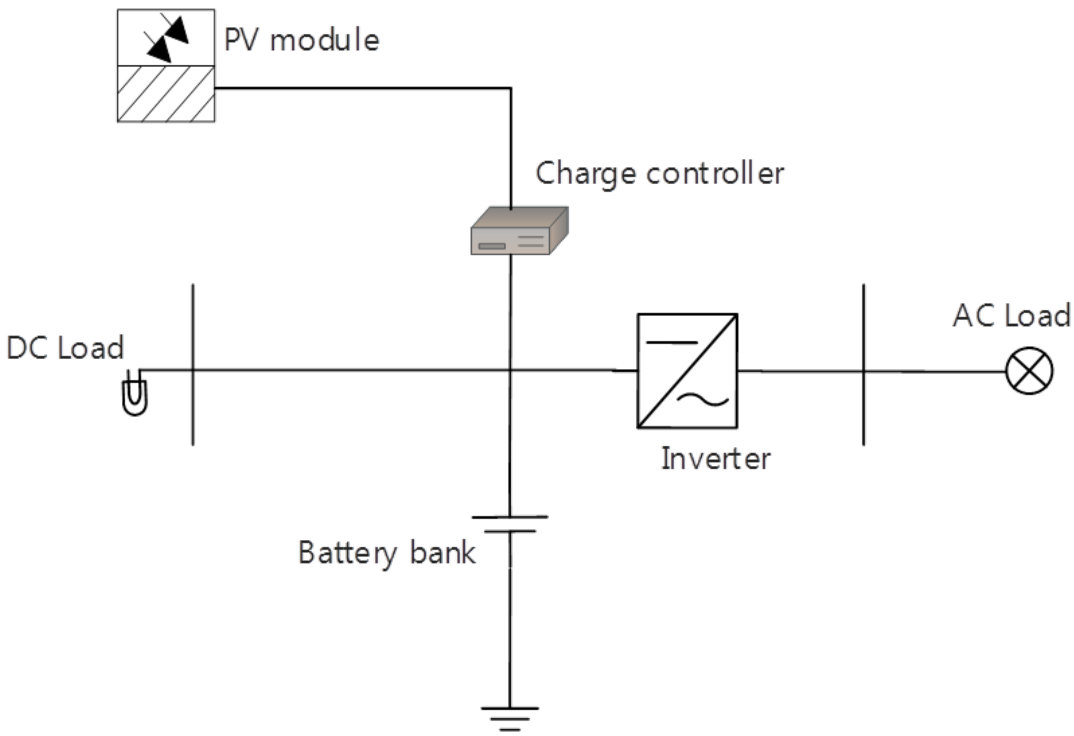

Figure 4.2: Schematic of a Standalone solar PV system

The components of standalone solar PV system include PV module, charge controller, battery, inverter and load. Stand alone or off-grid solar PV systems are permanently not connected to the utility power grid. They are used to generate electricity and make it available for usage through batteries storage via an inverter. PV panels generate electricity that passes through charge controller to charge a set of batteries. The energy from the batteries can be used directly to supply DC load or converted into regular usable AC power by an inverter to supply AC load as shown in figure 4.1. The choice between AC and DC usage usually depends on the size of the solar PV system and equipment availability. Generally, small systems are ones that mostly use DC power directly from the batteries.

4.4.2 Grid connected solar PV system

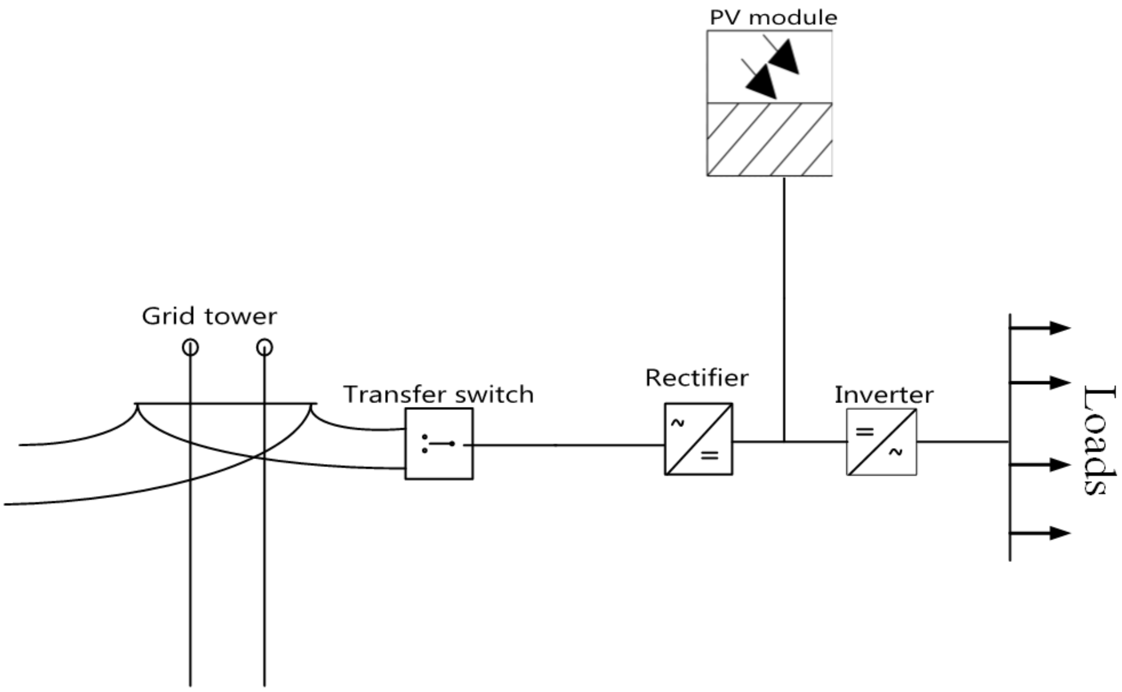

Figure 4.3: Schematic of a grid tied solar PV system

In grid connected systems the DC power from solar PV panels goes to a grid connected inverter which converts the DC power into AC power that is compatible with the power from the grid. The AC power from an inverter supplies the equipment connected to AC line. However, according to the mode of operations of grid connected system there are two types of grid connected inverter; grid interactive inverter and grid tied inverter [30]. Grid tied inverter is used in grid connected system which does not use battery for backup as it is presented in figure 4.3. Grid tied inverter supplies the load and feed the excess energy back to utility grid, therefore grid bill reduction. Grid tied inverter can be used for both small residential solar systems and large commercial solar systems. But, during grid power outage the grid tied

inverter is shut down immediately due to safety precaution.
Grid interactive inverter is used in applications where high level of reliability is a requirement. When power from utility is normal, grid interactive inverter operates as a grid tied inverter which supply the load and feed the excess energy back to utility grid. When power from utility is not available, the inverter operates as backup power source from PV panels and battery. Grid interactive inverter is used to provide a reliable backup power from renewables during power outages. As its counterpart, it is also used to reduce energy consumption from the utility network, hence the reduction of utility bills [30].

4.4.3 Hybrid system

A hybrid system can either be based on an off grid inverter or a grid connected inverter. Figure 4.3 shows an example of a hybrid of solar PV battery based system, diesel generator and grid. Power supply in hybrid system is from a combination of two or more power sources. For instance solar PV and other power sources like diesel generator and other renewable energy systems are frequently considered as hybrid systems. But, hybrid system can also be composed by renewables and power grid system which does not allow an injection of power from renewables into the grid; this application is in the grid networks where net metering policy is not in place. Hybridized systems of renewables are usually designed to operate in remote areas or islands where the cost of grid expansion is high. However, hybrid energy systems coupled with conventional energy source have also been proven to reduce the cost and simultaneously improving reliability of electrical power supply in many off-grid and weak grid connected locations [30].

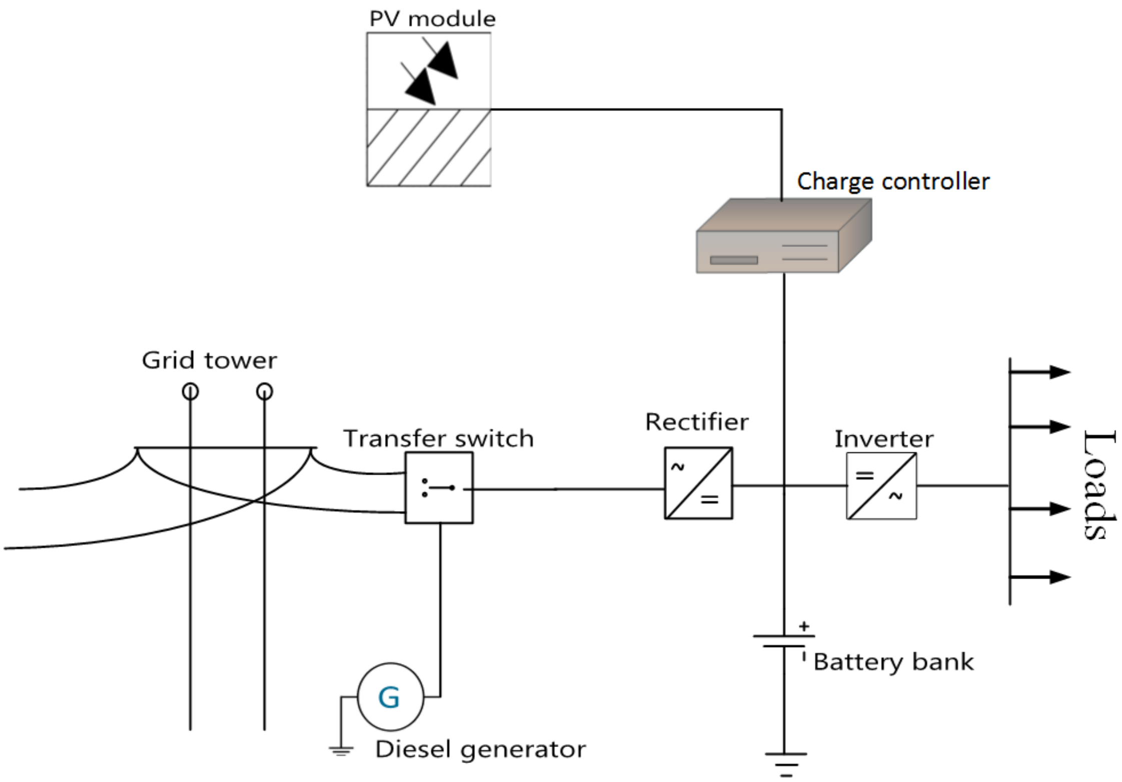

Figure 4.4: Schematic of a hybrid solar PV system

4.4.4 Impact of integrating solar PV into the grid at customer level

The usage of renewable energies is growing year to year around the world and is contributing to decarbonisation, energy security and electricity access. High penetration of renewables into grid contributes to reduction in green houses gases emitted in the process of energy production by use of conventional sources. On the other hand, to enhance energy security, utility companies are using diversification in power production such as integrating renewables into conventional power generation, thus reducing the volatility of fossil fuel, oil, gas, and coal market price. Renewable energies are often more feasible in remote area (where resources are available) far from loads or distribution lines; therefore transmission lines to connect renewables to the load or distribution lines are required. However, connectivity of renewables can easily be realized in isolated communities at cheap price compared to the cost of expending power grid and cost associated to line losses. Though renewables integration into grid has become popular; they can be observed in different perspectives. For example integration of solar PV into existing power system at customer level can be seen through voltage quality, interruption and power fluctuation phenomenon.

-Voltage quality

It has shown in [31] that the increment in PV penetration level induces an improvement in voltage drop and profile. On the other hand, the use of PV inverter contributes to transient voltage stabilization and voltage sag control [32]. However, an increment in penetration level of solar PV for a given power system has an optimal penetration level since level of renewable penetration varies with distribution systems and countries' power system characteristics. Therefore, it becomes technically advisable to analyze the acceptable penetration level in a given customer power system because high renewable penetration level has negative effects such as complication in protection scheme, demand supply balance and generation reserve requirement.

-Interruption mitigation

Interruption is a power quality phenomenon that results from the failure of power supply. The impacts of interruption can be severe due to its time of occurrence, its duration, its improvisation, its cause as well as type of consumer's electricity system [18]. For instance, effects of interruption in health facilities are quite different from industrial plant, offices and household. To mitigate interruptions, different technics are used. Such technics include use of uninterruptable power supply, two independent sources of power supply with static transfer switch, and distribution static compensator (D-STATCOM) device. To realize two independent sources of power supply; it is becoming practical to use solar PV and solar thermal to provide energy services during grid outages in countries with warm weather in order to improve power supply security and reduce pressure on local grid.

-Power quality

Power quality phenomenon is affected by a rapid variation in power supply. For an unstable power system, the use of solar PV may contribute much to the power fluctuation phenomenon. Fluctuation in solar PV power output can be caused by rapid change in climate conditions or poor synchronization of PV system and distribution power network. High PV penetration level in low irradiance conditions leads to the voltage dip [32] because any change in power supply from solar PV due to variation in solar radiation will affect the magnitude of the output voltage. High PV penetration during low demand leads to overvoltage and reverse power flow. To mitigate the fluctuation of output power due to variation of radiation; maximum power point trucking (MPPT) system is integrated in PV inverter where MPPT tries to operate solar PV at stable voltage whereas optimal PV penetration and load management are used to mitigate reverse power flow and overvoltage.

4.5 Assessment of load profile

A load profile in power system modelling is a depiction of the use of power throughout a certain period like a day, week, month or a year. The load profile illustrates the variation of energy consumption of electrical equipment(s) when are turned on or off, the load profile is used by electric utility campanies to plan the required electricity at a given time.

The load profile is constructed based on data obtained either from interviews or from measurement. The time resolution for data collected from interviews is coarse since people are not able to accurately respond at the exact time the electrical load are turned on and off, while data collected from measurement method improve time resolution and reliability of load profile [33][34].

For electrical load and PV generation profiles on the rate of residential, commercial as well as industrial in order to optimize PV size and PV-battery systems different resolution are used. For example high resolution like less or equal to ten seconds measured input data for PV generation and electrical load profiles are used for the analysis [34]. Studies show that the temporal resolution of load profile is more critical for the accuracy of the determination of residential houses rates than the resolution of the PV generation [35].

In addition, for solar PV system without backup system good results can be obtained by using fifteen minutes solar irradiance data, whereas the precision for electrical load profiles depends strongly on the type of load profile. The accuracy results for all kind of electrical load profiles can be obtained with sixty seconds. While fifteen minutes data can still be sufficient for load profile that do not exhibit most of their electricity consumption at power levels above 2kW. On the other hand, for solar PV with backup systems the influence of the temporal resolution on the rate of residential house becomes less distinct [35].

Briefly, depending on the load profile, temporal resolutions between 5 to 60 minutes data are resulted in good accuracy. Concerning optimal sizing of the PV power and the backup systems capacity a resolution of one hour is found reasonable. Concerning the sizing of battery inverter power of the backup system, a narrowed temporal resolution of at least 5 minutes is required [35].

5

Case: Energy system of Kolandoto hospital

The field study conducted at Koladonto hospital, thus far considered as the case study in this report, aimed to collect possible information on health facilities' electricity power supply that are useful to evaluate the feasibility of improving reliability of the existing power system.

5.1 Energy consumption at Kolandoto Hospital

During the field study, energy power system of Kolandoto hospital has been investigated in a way that the inventory list of all electrical equipments (any load that needs power supply during medical and emergency services and other related activities) was categorized into four groups according to health services they deliver.

The first group comprises lighting system which is dominated by florescent light tubes of 36W each; with few 18W LED (Light Emitting Diode) fluorescent light bulbs that recently penetrated into the system by replacing damaged incandescent light bulbs (60W). In the same category operational (surgery) lights are included. The second group is cooling system that embraces devices such as air conditioning units, fridges and fans, while heating systems is the third group that combines all boiling, heating and sterilization machines as well as laundry machines. Above to those three groups, the fourth holds together all infrastructural electrical equipments such as medical devices which do not fall into previous groups for example: X-Ray machines, diagnostic ultrasound machine, anaesthesia machines, electrical operation beds, etc. This category holds also office devices such desktops, laptops, printers, radios, scanners plus water equipments (pumps, suctions machines).

The energy consumption share of each group in the entire system is illustrated by the figure 5.1 below.

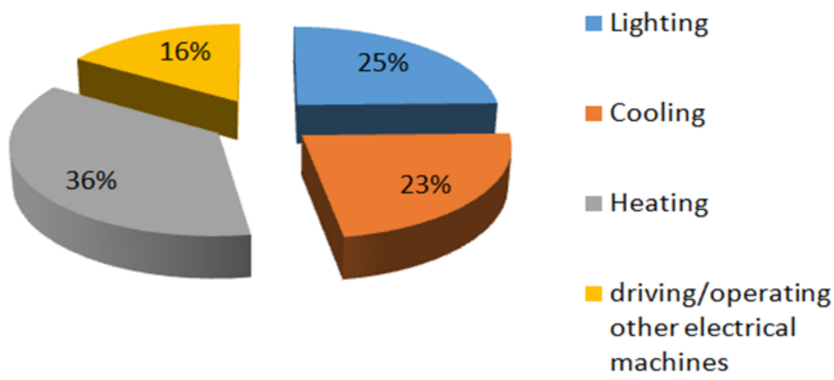

Figure 5.1: Utilities of electricity at Kolandoto hospital

The total energy consumption of the system was estimated at 705kWh per day whereas the installed load capacity is 135kW for the whole system. The peak consumption is obviously occurring during a day with 489kWh, approximately 69% of daily energy utilization while the night accounts 216kWh or 31% of the daily energy.

5.2 Design of solar PV system

A solar PV system is designed based to the site weather conditions, mounting, shading, module orientation, module tilt, required area, future considerations and grid cod. Each parameter above has been given much consideration during this design. The sub-chapter presents assessment and sizing results of a solar PV that will be proposed to mitigate interruption at Kolandoto hospital during power outage. Tanzania regulations about electricity do not allow an injection of power from customers to the network grid. Therefore, limitation to grid tied systems is also considered in this design.

5.2.1 Assessment of configuration design of a hybridized solar PV

In order to assess effectively the optimal design that is feasible, HOMER (Hybrid Optimization Model for Multiple Energy Resources) software is used. HOMER is a micro-power optimization model that simplifies the task of evaluating designs of both off-grid and grid-connected power systems. When you are designing a power system, it is required to make decisions about the best configuration of the system. However, the large number of technology options and the variation in technology costs without forgetting availability of energy resources make these decisions more difficult. Therefore, simulations are carried out to compare possible configurations and evaluate them based on their economic and technical merits. After evaluating possible available energy sources at Kolandoto hospital; hybrids of solar PV and one or more energy sources are investigated in next paragraphs.

-Hybrid of solar and wind energy

The wind speed is the main factor to harness the power from the wind. But wind available at Kolandoto area is not sufficient to be used in power generation. However, solar radiation intensity above 2000kWh/m^2/year is available in Kolandoto region and it can be used to generate either electricity or heat. On the other hand wind and solar are both intermittent sources of energy. Therefore it is not easy to predict a production from these sources that can meet peak demand at any time. According to [36], five tests of hybrid systems has been conducted at different locations where wind alone and solar alone have been compared to other hybrid systems. Results in [36] have found that hybrid systems are more effective than only solar system or wind system.

-Hybrid of solar and hydroelectric energy

Hydroelectric energy is generated by converting water flow into mechanical energy that drives a turbine. The turbine shaft rotates together with the generator rotor that induces a voltage in the stator. Hydropower technology requires sophisticated civil work on its hydrology to produce electricity. Therefore, hydrology and requirement to form hydraulic head to produce hydroelectricity is not possible at Kolandoto. But on the other hand, hybrids of solar and small scale hydroelectric energy have been proved in [36] to be able to supply energy both cost effectively and environmentally in other rural electrification.

-Hybrid of solar and diesel

A diesel generator uses petroleum to produce electricity. But, diesel emits harmful greenhouse gas to the environment and there is a considerable price associated to the use of diesel. Hybridized system of solar and diesel have been proven to be used in cost cutting and reduction in gases emissions [36]. However, this option become weak as the demand is increased though it can work at Kolandoto hospital as back up (few hours) during the grid power outage.

-Hybrid of solar with two or more other sources

Hybrids of solar with two or more other sources are more preferred though it becomes more complex to design an optimal system. In [36] studies have shown that more sources in hybridized system makes it more cost efficient and reliable. Thus, the combination of solar, battery, grid and diesel is chosen to support energy system at Kolandoto hospital where interruptions and electrical bills are alleviated. Modelling and optimization by HOMER will be carried out to validate the decision from calculations. Calculations are performed in the next section in order to have an idea about equipment size that will be used during optimization and further design analysis.

5.2.2 Scenario A: Solar PV system sizing results for critical loads

In the following scenario the AC energy consumption for critical loads is calculated during one hour of operation. Energy consumption computed by considering mean operation power values is reflected as scenario A1 and energy consumption computed by considering nominal power rating values is reflected as scenario A2. Derating factors presented in table 5.1 below are based on weather conditions and site characteristics of Kolandoto region.

Table 5.1: Reference conditions/Assumptions

#	Parameters	Value
1	Inverter efficiency, η_{inv} [%]	85
2	Module havest efficiency, M_{pv} [%]	76
3	Peak sun hour, Ir [h/day]	5.6
4	Day of autonomy, Aut	1
5	Voltage, Volt	12
6	Depth of discharge, DOD [%]	70
7	Shading factor, S_h [%]	100
8	Tilt and orientation factor, T_{or} [%]	90
9	Battery efficiency, B_{att} [%]	80
10	Battery temperature efficiency, T_{coeff} [%]	90
11	PV Module rating [Wp]	320
12	Battery [V/Ah]	12/245

Inverter efficiency of 85% is taken due to the idea that inverter efficiency reduces when the inverter is full loaded. Module harvest efficiency of 76% is taken due to the fact that Kolandoto area has high chance of dirty on the roofs and in most case the temperature is beyond 25^{o}C. Since the worst insolation at Kolandoto is 5.6kWh/m^2/day (when PV is tilted to 18^o) [37]; the number of hours that the sun is shining at its peak (Ir) of 1kW/m^2 is 5.6h/day. One Day of Autonomy is considered due to the presence of grid power supply at Kolandoto. 12V nominal rating of a battery is used in the next calculations due to high voltage benefits. The battery chosen here is 12Volts long life Gel 245Ah. The depth of discharge of battery considered is 70% in order to maintain state of charge at high level, hence longer battery life span. Battery temperature coefficient and battery efficiency are 90% and 80% respectively.

Shading factor of 100% is assumed due to the fact that the buildings at Kolandoto area are flat and not tall. Trees are also not many and are not tall. Tilt and orientation factor of 90% is assumed. Since Kolandoto is located at -3^o latitude implies that the site is close to the equator in the southern hemisphere. Tilt and orientation in these situations are of less influence, but 15^o to 20^o of tilt angle could be the best option and northern orientation is preferable to collect enough irradiations. Sunpower SPR-320E-WHT-D (320W) solar module with 1.6 m^2 surface area, power rating of 320W, short circuit current 6.24A and nominal voltage of 48V is chosen.

Scenario A1

-Solar PV array
AC energy consumption is 8.2kWh/day. This is the energy required during one hour of running time and it is calculated from critical loads using mean power operation values. Therefore, according to the equation (4.1) and values in table 5.1 above, the total derating factor ρ_{loss} will be 0.55. Again, using equation (4.4) and considering table 5.1; PV array is 3.2kW and number of PV modules is 10.

-Battery
The size of battery is calculated by using equation (4.5). Taking into account the values stated in table 5.1 and AC energy consumption of 8.2kWh/day; the battery capacity is 1278Ah which gives 6 batteries of 245Ah each.

-Charge controller
Controller's voltage will be the same as the inverter voltage (48V in this case), but the current of the controller is 30% over the short circuit current (Isc) from the PV array as seen in section 4 above. Since the short circuit current of one module is 6.24A and 10PV modules are considered as one string; the charger controller's current is 81A.

-Inverter
Since the AC power load requirement is known, the inverter power output rating is 30% over the AC power of the load. In this case the AC power is 11kW and the inverter power output will be 15kW. This shows that 5Vitronics Controls solar hybrid inverters (nGreen 3kVA/48V) are required.

Scenario A2

Doing the same calculations as per scenario A1 for PV array, battery, charge controller and inverter where the power values are from equipments' name plates instead of mean operation values; different results have been found. In this situation the computed AC energy consumption is 9.6kWh/day. Therefore, PV array is 3.7kW, number of module is 12, PV modules' placement surface area is 19.2m^2, battery capacity is 1499.13Ah that is equal to 7batteries with 245Ah each, and charge controller current capacity is 97.4A while inverter output power is 18kW.

Note that in both scenarios A1 and A2 the equipment running time is still one hour per day and the diversity factor/simultaneity factor (installed load over running load) of the load is regarded as 1.3 and 1.4 respectively. All these values of diversity factors are acceptable for designing electrical equipment in the category of general power facilities where health facilities can be found. A higher diversity factor corresponds to larger electrical components [38].

5.2.3 Scenario B: Solar PV system sizing results for total loads

In the following scenario (B), the total AC energy consumption of all electrical equipments is calculated over the period of one hour and twenty four hours of operation. The time duration of using an equipment over one hour is considered as scenario B1 while twenty four hours is considered as scenario B2. In both scenarios (B1 and B2) the nominal power rating is used instead of mean operation power.

Scenario B1

In the following scenario, AC energy is 105kWh while AC power capacity is 145kW. Using the table 5.1 and calculations as per scenario A; the size of PV Array is 40kW, number of module is 125, surface area to accommodate PV modules is 200m^2, 67batteries and 16charge controllers with current capacity of 50A are required. The inverter power output is 190kW which means 64Vitronics Controls solar hybrid inverters (nGreen 3kVA/48V) are required.

Scenario B2

Calculations in this scenario are performed based to twenty four hours of running time. Therefore, the size of PV array is 280kW, number of PV module is 875, surface area is 1,400m^2, 466batteries and 110charge controllers with current capacity of 50A are required. The inverter power output is 190kW which means 64 Vitronics Controls solar hybrid inverters (nGreen 3kVA/48V) are required.

Table 5.3: Summary of total loads' equipment sizing; scenario B

	Scenario B1	**Scenario B2**
Number of PV module of 320W	125	875
Surface area required (m^2)	200	1,400
Number of batteries rated 12V,245Ah	67	466
Number of charge controller rated 50A	16	110
Number inverters Vitronics (n Green) 3kVA/48V	64	64
Total estimated capital cost (USD)	**178,441**	**1,298,950**

Table 5.2: Summary of critical loads' equipment sizing; scenario A

	Scenario A1	**Scenario A2**
Number of PV module of 320W	10	12
Surface area required (m^2)	16	19.2
Number of batteries rated 12V,245Ah	6	7
Number of charge controller rated 50A	2	2
Number inverters Vitronics (n Green) 3kVA/48V	5	6
Total estimated capital cost (USD)	**14,370.2**	**17,419.2**

5.3 Installation layout

During electrical installation, wiring layout is important due to the fact that complication and confusion are reduced. Therefore, the installation layouts of solar PV components that could be integrated in the existing power system at Kolandoto hospital are presented in two options. The installation layout called “option one” will be used where critical loads and non-critical loads are separated (scenario A). Non-critical loads will only get power supply from the grid or diesel generator while critical loads will be supplied by solar PV system and/or grid-diesel generator. The installation layout called “option two” will be used for a decentralized system where there is no separation of critical and non-critical loads (scenario B).

5.3.1 Option one

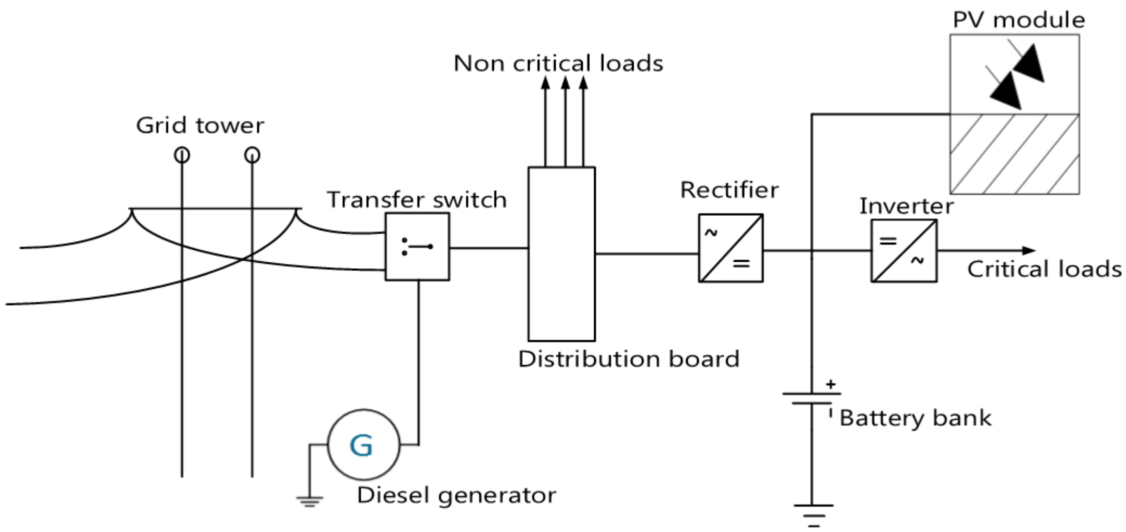

Figure 5.2: Schematic of a proposed hybrid system

How the system works

The hybrid inverter presented in figure 5.2 works as standalone inverter when batteries charge from module and works as grid connected inverter when batteries charge from the AC supply. AC supply can be either the grid or diesel generator. The hybrid inverter has a build-in bill reducing protocol that switches off the AC supply when the batteries voltage charges to 14V [39]. At batteries’ state of charge of 100%, via inverter; solar power is used alone to feed the critical loads.

When the solar power is not enough to sustain the AC load, the inverter draws power from batteries. When batteries are discharged to 60% of its capacity, the hybrid inverter switches on the main AC supply and batteries get charged from both AC supply and solar module. When the voltage of batteries reaches 14V, the same cycle repeats [39]. Note that 40% battery capacity is useful when there is no main AC supply and no solar power available, therefore the unit will work in battery mode and shutdown when the battery voltage is below 10.5V. The critical AC loads are separated from less critical loads at distribution board to lower the cost and technical challenges of solar system that would be required to support all AC loads.

This capability is possible for Vitronics controls hybrid inverter with maximum capacity of 3kVA as well as OPTI hybrid inverter of 11kVA maximum capacity each. The good thing with the Vitronics hybrid inverter is its capability of being paralleled.

5.3.2 Option two

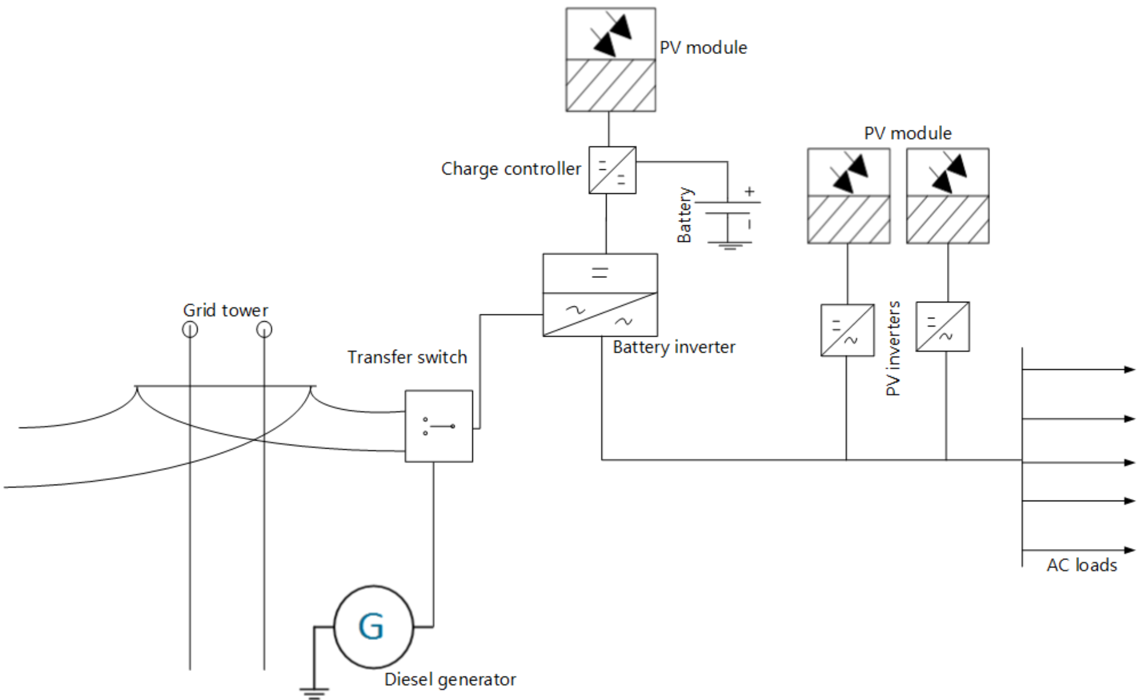

Figure 5.3: Schematic of a proposed hybrid system

According to the site characteristics of Kolandoto hospital, it could not be easy to find a unique place to accommodate solar PV system that can support the energy required by all loads. Therefore a decentralized system presented in figure 5.3 above would be the best option in these conditions. The most advantage a decentralized system presents over a centralized system is the effective surface area. More house's roofs or dispersed structures can be used to accommodate more PV modules. A disadvantage of this design is the cost promoted by the use of two different technologies of inverters.

A battery inverter as called in figure 5.3 above is a hybrid inverter with capacity of preventing the injection of the power from the AC power generated by remote PV into the grid. This capability complies with the grid rules in Tanzania where two ways metering system is not in place. A PV inverter is a normal grid tied inverter that converts DC power from PV module into AC power. This design can work well with SMA-Sunny Island 8.0H hybrid inverters with its accessories. The maximum power this system can deliver is 300kW if many battery inverters and many PV inverters are used.

5.4 Modelling of solar PV and other available power sources

In accordance with energy demand analysis and design calculations carried out in the previous parts, it was necessary to perform economic, environmental and technical comparison of possible power supply (configuration). To achieve these, available power sources at Kolandoto hospital plus solar PV system are modelled. The modelling is performed according to the figure 5.4.

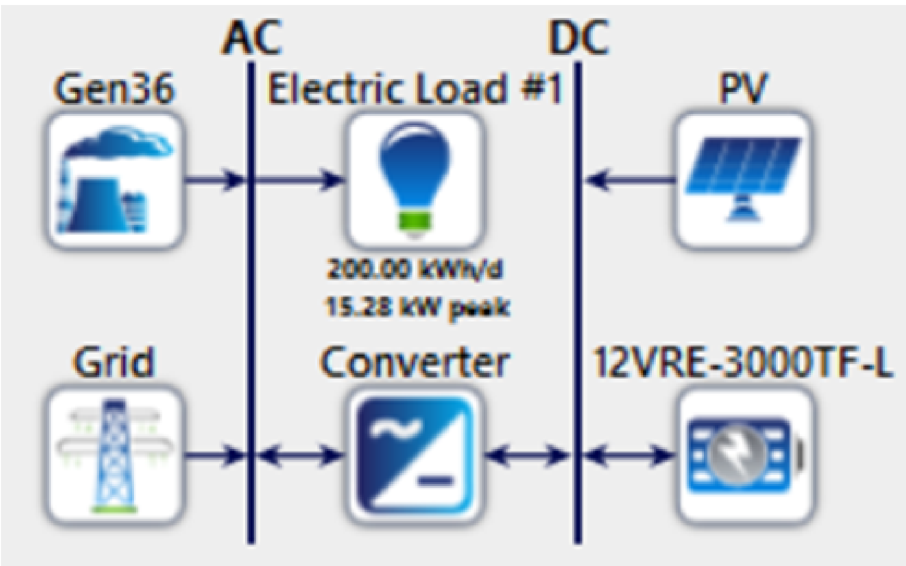

Figure 5.4: Structure of system model

The comparison of possible configurations was executed by use of simulation tool (HOMER) where different inputs such as components' electrical specification, capital cost, maintenance and operation cost, and emissions are evaluated in order to find an optimal configuration.

Table 5.4: Components' electrical inputs

Solar PV	Generic flat plate PV	3.2	kW
Diesel generator	36kW Genset	36	kW
Battery	Discover 12VRE-3000TF-L	8	2 strings
Converter	System converter	15	kW
Grid	Grid	17	kW
Load	Constant load	8.2	kW
Outages	Frequencies	365	Times/year

Table 5.5: Costing inputs

	Capacity (kW)	**Capital cost ($/kW)**	**Replacement cost ($/kW)**	**O&M cost**
PV	3.2	1400	1400	140 ($/kW.year)
Diesel generator	36	1000	1000	0.80 ($/hr)
Converter	15	501	501	50 ($/kW.year)
Grid	17	-	-	0.10 ($/kWh)
	Quantity	**Capital cost ($)**	**Replacement cost ($)**	**O&M cost ($/year)**
Battery	8	588	588	58

Table 5.6: Emissions inputs

	CO_2	CO	UHC	PM	SO_2	NO_x
Grid power [g/kWh]	586	-	-	-	2.74	1.34
Diesel generator[g/L]	-	2663.5	0.72	0.49	2.2	58

After several simulation attempts, four feasible configurations were found where each configuration contains optimal specific characteristics as illustrated in the table 5.7 below.

Table 5.7: Possible power supply configurations

Order	**Architecture**					**Possible power supply configurations nomenclature**
	Solar PV 36kW	Diesel Generator 36kW	Battery 8units	Grid power 17kW	Inverter 12kW	
1st	√	√	√	√	√	Trigeneration system
2nd		√	√	√	√	UPS system
3rd		√		√		Baseline case system
4th	√	√		√	√	Trigeneration system without batteries

Possible power supply configurations at Kolandoto hospital

As shown in the table 5.7, possible power supply configurations at Kolandoto are trigeneration system, UPS system, base line system and trigeneration system without batteries. The trigeneration system is composed by solar PV, diesel generator, grid, inverter and batteries while the trigeneration system without batteries comprises solar PV, diesel generator, grid and inverter. The UPS system comprises diesel generator, grid, inverter and batteries. The base line system consists of diesel generator and the grid.

All four power supply configurations could be a solution to power instability at Kolandoto hospital. However, there is a ranking among them based to the technical and economic merits of each configuration. For this reason the table 5.7 ranks all four configurations mostly based to their economic impact. Though the economy is considered as leading indicator in the ranking, there is a technical implication related to what presented in table 5.7. For example the first configuration has the lowest diesel generator working hours (547hours/ year) and lowest energy purchased from the grid (61Mh/ year). Though the capital cost of the first configuration looks higher, the operations and maintenance costs are lower compared to the other four configurations.

According to the insecurity of power supply at Kolandoto hospital, the trigerenation system is the first best solution due to the fact that three sources of power are used to generate electricity. If one of them is out of service the remaining two sources can support the load requirement. Furthermore, the batteries store energy that can be used in the obscene of all other power sources.

The second solution is the UPS system which is composed by batteries that are supplied by either grid or diesel generator via the inverter. This configuration is commonly used in data centres, hospitals, banks, and other sensitive loads that need uninterruptable power supply. The main reason that makes this configuration the second is the absence of solar PV in the process of power production.

The third solution is the base line system that comprises diesel generator and grid. The base line system has been used for several years to improve the reliability of power production in different countries. It requires automation of the diesel generator or technician to switch on and off during power grid outage and restoration. It is ranked on the third position among the other four configurations due to its high operation and maintenance cost.

The forth configuration is the trigeneration system without batteries. The working principal of this configuration is the same as the one of the first configuration with one main difference. The difference between them is the lack of energy storage devices in the trigeneration system. Another important note is for the third and the forth configurations, which is a short interruption when the main (grid) fails due to the transfer time from the main to the second source.

Usually there are several ways of ranking or evaluate economy of projects about power systems by looking on several costs as indicators. For example those costs can be; costs of buying equipments (PV modules, batteries, inverter, diesel generator), fixed and variable operating cost as well as maintenance costs (O & M) (financing cost), and the levelized cost of the energy. Other evaluations look up on net present cost as well as payback period to study the feasibility of the project.

All above are the reasons this report focuses only on the levelized cost of energy (LCOE) and net present cost to compare all four possible configurations of power supply particularly baseline system (grid and diesel generator) and trigeneration system (solar PV, diesel generator, grid power with batteries and inverter). LCOE means the price of electricity required for the entire period of the system where revenues would equal the costs, including making a return on the capital invested equal to the discount rate, thus 7% was used as discount rate in this case.

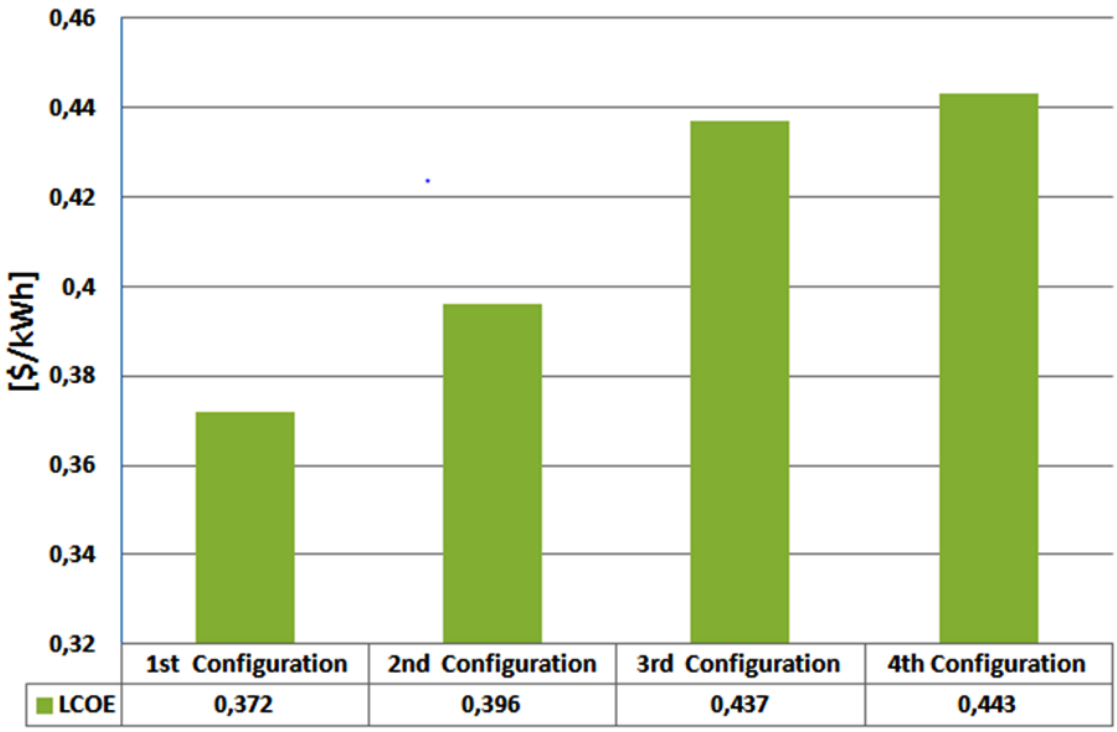

Figure 5.5: LCOE for power supply configurations

In addition to that, net present costs for all four configurations have the same pattern with levelized costs of electricity.

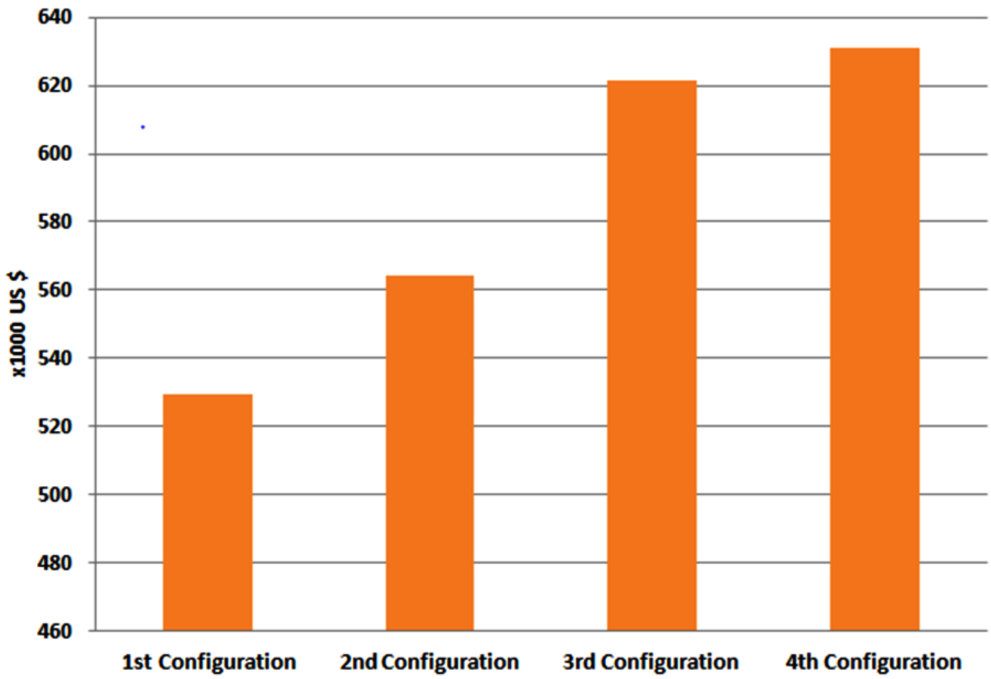

Figure 5.6: NPC for power supply configurations

On the other hand, emissions comparison basis is adopted in this thesis to figure out which power supply system that emits less or more dioxide carbon (CO_2), monoxide carbon (CO), dioxide sulphur (SO_2) and mono & dioxide nitrogen (NO_X)quantities per unit of time [kg/year]. Besides the mentioned emissions, simulation tool displays also the amount of unburned hydrocarbon (UHC) and particulate matters (PM) emitted per each configuration.

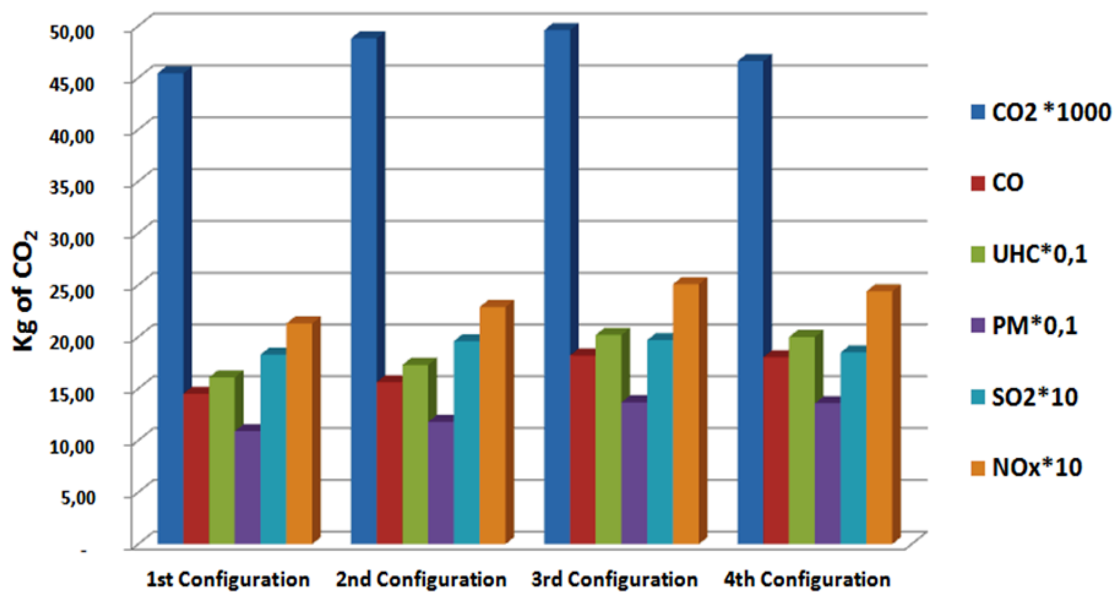

Figure 5.7: Emissions for power supply configurations

Energy production of hybridized system versus baseline system

According to the simulated results, annual electrical production for each sources combination can be observed. For instance, the yearly energy production of the combined sources that comprises solar PV, grid power and diesel generator show that solar PV system has produced 5.6MWh, while diesel generator and grid have generated 5.7MWh and 61MWh respectively. The running time of the diesel generator is 547hours per year which stands for 7.7% of the total energy supply, and solar PV has a running time of 4,430hours per year and takes 7.8% of production whereas 84.5% of total production remains for the grid.

The simulated results have shown again that the autonomy of the battery system is 2hours with usable nominal capacity of 16.46kWh. The state of charge of batteries along 25years is over 50%, thus a prolonged batteries life time. The yearly energy production of base line and trigeneration systems are presented in the figure 5.8.

On the other hand, the simulation results from the baseline system (grid and diesel generator) have shown that diesel generator worked 744hours with total energy production of 7MWh per year while the grid has produced 66MWh per annum.

This shows that the diesel generator cover 9.6% of the total production where the remaining 90.4% is from the grid as illustrated in the figure 5.8. Therefore, when solar PV system is integrated in existing power system; the diesel generator and grid will produce less power which will lead to the improvement in power supply reliability and electricity bill reduction.

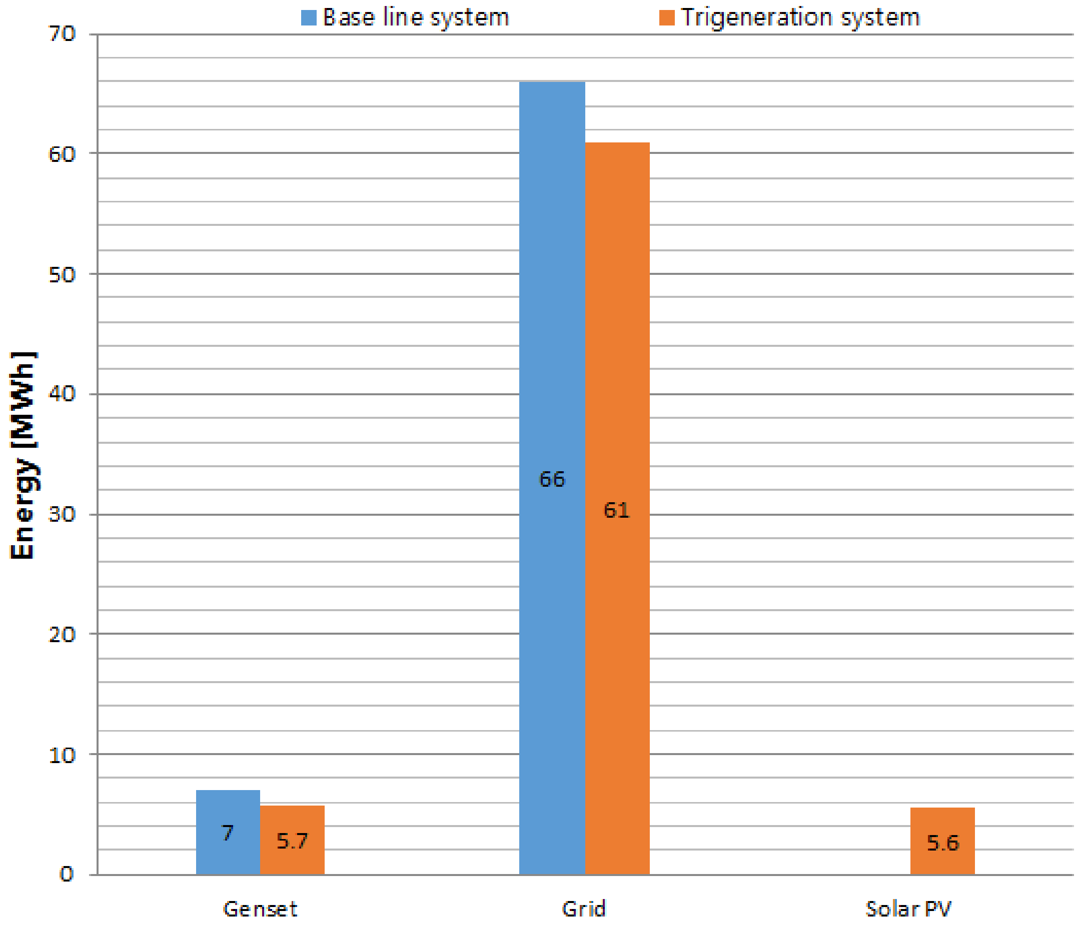

Figure 5.8: Energy production of hybridised system versus baseline system

It is interesting also to look at other parameters like AC operating capacity and AC required operating capacity to sustain the load. Required operating capacity is the required operating reserve capacity plus the electric load capacity while the operating capacity is the total amount of electrical generation capacity that is ready to produce electricity at a given time, it is therefore the maximum possible amount of electricity that the system could serve at a particular moment.

During simulation, it was necessary to ensure that the system's operating capacity is always sufficient to supply the primary load and the required operating reserve. For this reason, the operating capacity had to be greater than the electric load. For 8.2kW load capacity, 17kW is the minimum AC operating capacity required to supply the load over the project's time period under specified reliability conditions while 0.4kW is the lowest spike noted as indicated in figure 5.9. It is worthy to note that 0.4kW is achieved for a very short time; therefore it has found through several simulations that at AC power value from grid less than 17kW, the simulation was infeasible. This, it results from the number of outages and variability of the load assumed in simulating tool where the peak load is 15.3kW.

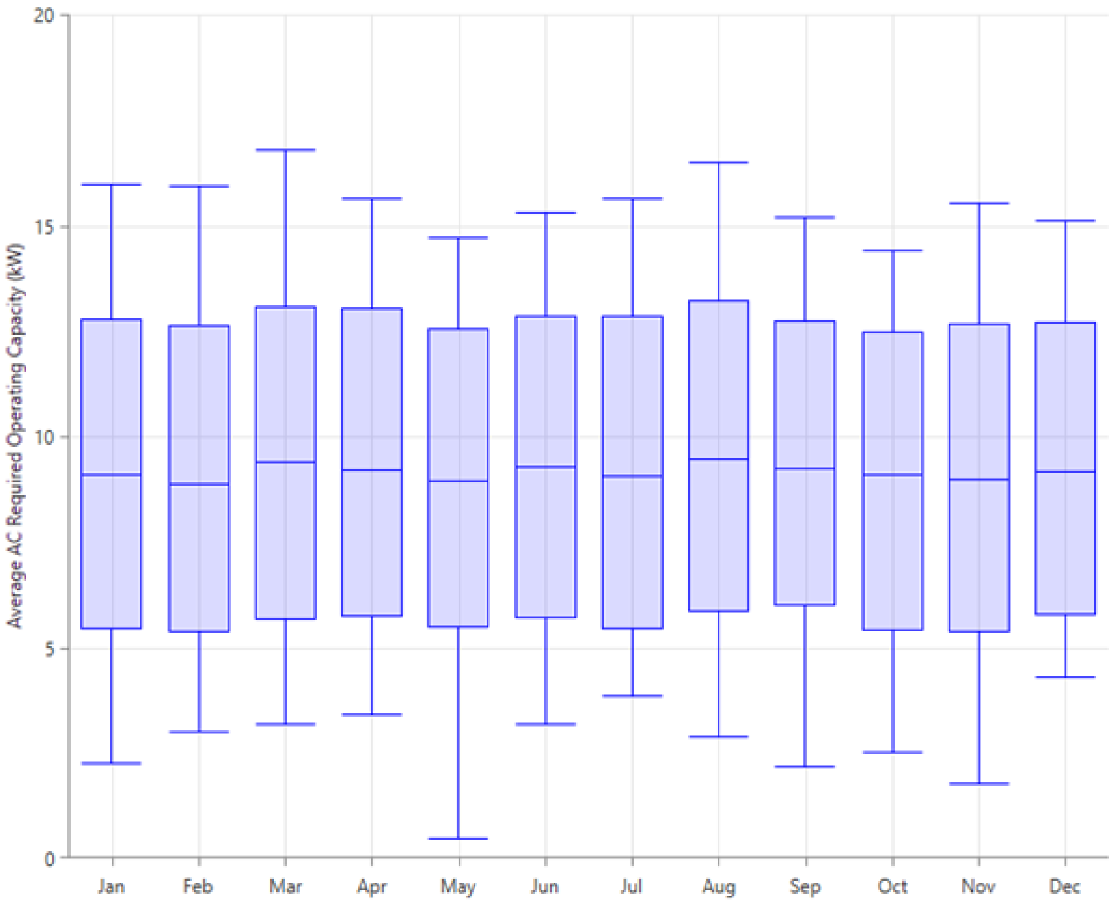

Figure 5.9: AC required operating capacity

In the same way the Maximum possible AC operating capacity is found to be 53kW. This value can be attained when the diesel generator (36kW) and grid (17kW) are simultaneously considered as dispatchable power source where 3.2kW from solar PV is not considered because solar PV is not a dispatchable power source. According to reliability considered in simulations, the grid capacity is not always available due to power outages; those outages are the consequences of reduction in AC operating capacity. Reduction of operating capacity in the event of outage is covered either by a diesel generator or PV system.

In conformity of AC required operating capacity presented by figure 5.9; yearly load profile was also generated. Initially AC load for all critical equipments was totalised from the inventory work as 8.2kW per hour, but by considering possible variations which can occurred 10% variations between day to day and 40% variation within time step were randomly taken into consideration. As result, the peak load was seen during the surgery operation hours that usually take place from nine to twelve morning of each single day, whereas the AC minimum load were observed during break time and night hours as illustrated by a portion of 24 hours of yearly load profile, figure 5.10.

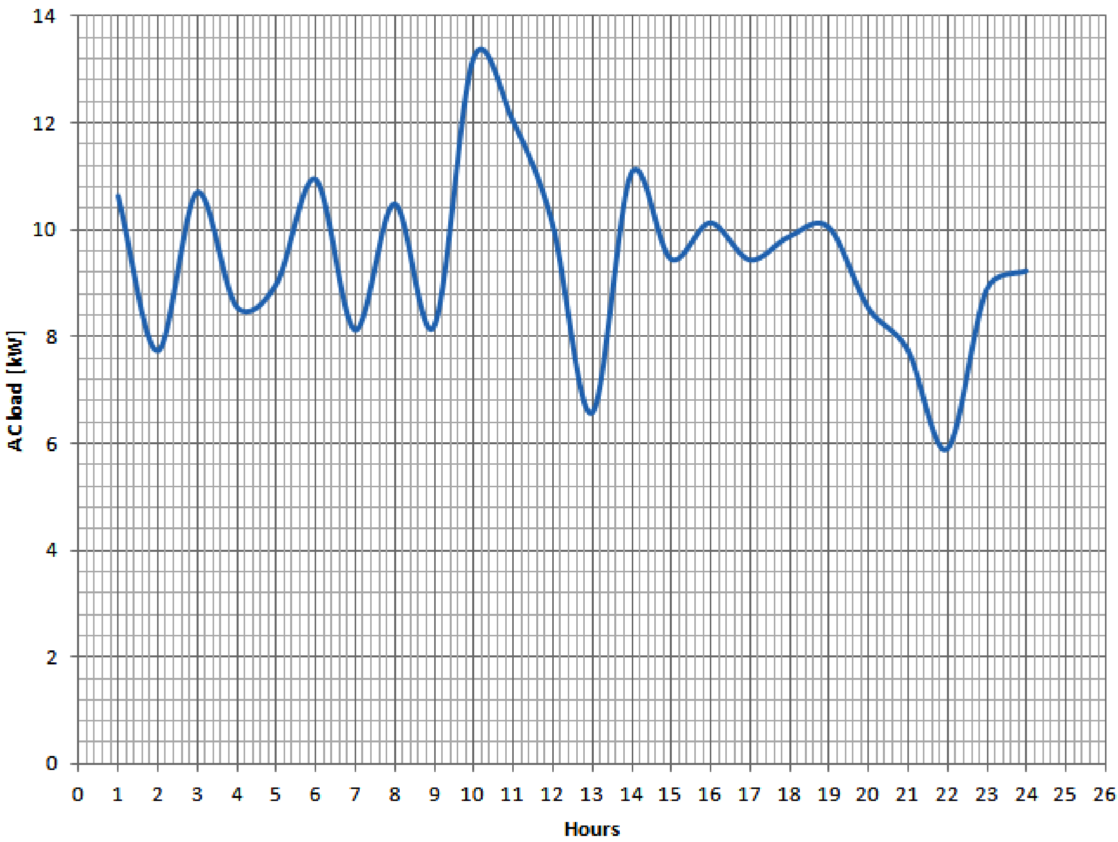

Figure 5.10: Load profile for a single day

6

Discussions

6.1 Background

It has been found in this work that Tanzania has diversified potential resources in renewable energy, which are exploited not enough to alleviate the gap between energy demand and supply due to inadequate financial means and skilled labor. For instance, only 12% of the hydropower potential is exploited whereas only 380MW is from geothermal. The off grid PV system accounts 6MW which is distributed among 64% of the population without access to the grid power while grid connected PV generates 1800MWh per year. The average irradiation in Tanzania is estimated above 5kW/m^2/day which means that more than 5hours per day the sun shines at 1000W/m^2. This emphasizes how renewables especially solar PV are not exploited, and yet solar is among the abundant sources of energy all over the country. Even if there is a lot of effort like encouraging private investors in energy production, and reducing tax on solar equipments to increase the solar PV production share to 20% of total energy in 2025; one can see that a lot of things has to be done to achieve this goal.

Apart from hydropower, geothermal and solar PV that are viable renewable sources; researches have also proven that Tanzania has potential in wind energy in some regions. Wind speed of 8 to 9m/s is available at a height of 30m according to MEM, TANESCO and REA. The later (Rural Energy Agency) has a mandate to promote the access to electricity in rural areas by using solar PV, solar thermal, micro-hydro, wind, biomass, geothermal and conventional sources. But, REA is getting challenges of financing all viable projects for each renewable technology and available financial means are not equally distributed among energy sources.

REA and government are sensitizing investors to produce power that can be sold to the community via national power grid or island network at the same time encouraging individuals to generate electricity for their own use. This is the reason some individuals, schools, hospitals and government institutions are trying to invest in autonomous power production by use of local available energy sources. There is no limitation in Tanzania regarding autonomous power production. The challenges may arise when you are shifting from autonomous system to interconnected system (grid connected system). However, the limitations for interconnecting individual's power source with national grid discourage people who may want to enjoy benefits of net metering.

This explains how standalone solar PV system is taking advantage over other types of solar configurations presented in subsection 4.3 above especially in remote areas. If regulations can be revised and accept the use of two way energy metering system, people could take benefits of integrating solar PV system into grid. Considering that 36% of the population in Tanzania is connected to the utility grid; no doubt a certain percentage among this population would try to reduce their bill of electricity at the same time improving the reliability of their power systems. Generally the integrated solar PV system can be more advantageous in places were wind, hydroelectric or geothermal are feasible. In places where reliability issue is significant; storage system like batteries are used. But, there is a drawback of the hybridized battery based system which is the capital cost and maintenance cost associated to the batteries. However, the hybridized battery based system presents financial benefits in long run as it is proven in this work and by other researchers.

The hybridized solar PV system is proposed to be used at Kolandoto hospital where energy system is mainly relying on grid power and diesel generator that works during grid outages. As it is explained in chapter 5; the occurrence of outages are estimated between one and two hours per day. This is an averaged time that could even be more or less in real time. The improvement of grid reliability can be done by putting in place redundancy in distribution power network. This implies the use of two Independent sources of power supply in order to realize N-1 working conditions. N-1 solution looks unfeasible to Kolandoto area due to the priority and weakness of infrastructure in power system of Tanzania. But the integration of alternatives sources (to realize N-1 supply) in the existing power system can be possible since it can start by small scale to larger scale as it is presented in this thesis.

6.2 Technical

At Kolandoto hospital lighting uses 25% of the total energy (705kWh per day), biomedical equipments and staff offices machinery use 16%, heating and cooling use 36% and 23% respectively. According to the hospital management among these loads, they are some that are considered as less important and very important based on usage in saving or preventing risk to patient's lives . Those are considered as very important are called critical loads with 11kW installed capacity while running capacity is 8.2kW. The energy consumed by critical loads during one hour of operation is 8.2kWh.

Regardless the circumstance that brought an idea of considering only 8.2kWh, during the solar PV sizing, the total load at hospital has also been considered in order to see the impact of large solar system over a slimmed one in the same working conditions. Recall that the total load consumes 105kWh per hour which shows that critical loads during one hour consume 7.8% of the total load. Simulation results from sizing values for solar PV array, inverter and battery show that the first optimal system configuration is obtained from a combination of grid, diesel generator and solar PV battery based system in both slimmed and large system. Note that outages are considered randomly and simulated to evaluate the reliability of the system. It has been found that these outages contribute much on the cost and size of the power system.

There are a lot of interesting parameters to observe in the results when you are shifting from slimmed load to large load; such parameters are the reduction of levelized cost of electricity from 0.391$ to 0.235$ and the operation hours of a diesel generator from 547h to 22h. Without detailing all important parameters; the parameters highlighted here are the image of real advantage of increasing renewable fraction in electricity production. However, there are drawbacks noted like high initial capital cost and high surface area to accommodate a big number of PV modules required.

The calculated values of solar PV system are usually useful for standalone systems. The true formulation for sizing a hybridized system was not used because it was not easy to find a generic and acceptable formulation due to lack of a well established approach for hybrid systems. However, the simulating tool HOMER has been used to simulate and optimize sizes of equipments based on the minimum expected equipments' sizes.

During 24hours of operation per day over the life time of the project (25years); the results from optimization and simulation show that critical load (8.2kW) will be supplied by 8.7kW from solar PV. Where 15.3kW is the size of an inverter, 36kW is from diesel generator (with running time of 21hours per years), 17kW is the grid capacity and 8kW is from 30batteries of 245Ah, 12V each. In this circumstance the LCOE will be 0.220$. Whereas, simulation results based on calculated values using standalone approach (without optimization), for 24hours of operation per day had shown that the existing system (diesel generator and grid) would be the cheap option due to the oversizing hence the cost of solar PV components. This must not be confused to the calculated values in subsection 5.2.2 which are based to one hour of operation.

In the same conditions as for critical loads, optimized results based on total load (105kW) have showed that at LCOE of 0.189$, the load will be supplied by 165kW from solar PV, 160kW is the size of an inverter, 36kW is from diesel generator (running time is 371hours per year), 210kW is the capacity of grid and 105kW is from 250batteries of 245Ah, 12V each. Therefore, one can see that the calculations results presented in table 5.3 (scenario B2) by using convention formula will lead to extremely high values of solar PV systems, hence standalone formula leads to size an expensive system.

Different load modelling has been performed in order to see how the load increment affects components of solar PV system such as size of PV array, inverter, number of batteries and generator's working hours. Note that the diesel generator capacity and grid capacity are assumed to be constant at 36kW and 17kW respectively. The proposed solar PV system's components and criticalloads at Kolandoto hospital have been taken as base where different percentages of load increment have been simulated in order to find optimal values of each system component. The increment of load has induced the rise of required capacity of different system components as shown in figure 6.1 apart from some irregularities noted. For instance, the generator working hours' curve goes high fast at relatively low values of solar PV array and batteries while it tends to fall at higher values of solar PV and batteries. Therefore, high solar PV penetration implies low operating time of the diesel generator thus less fuel cost and fuel dependency in electrical power production.

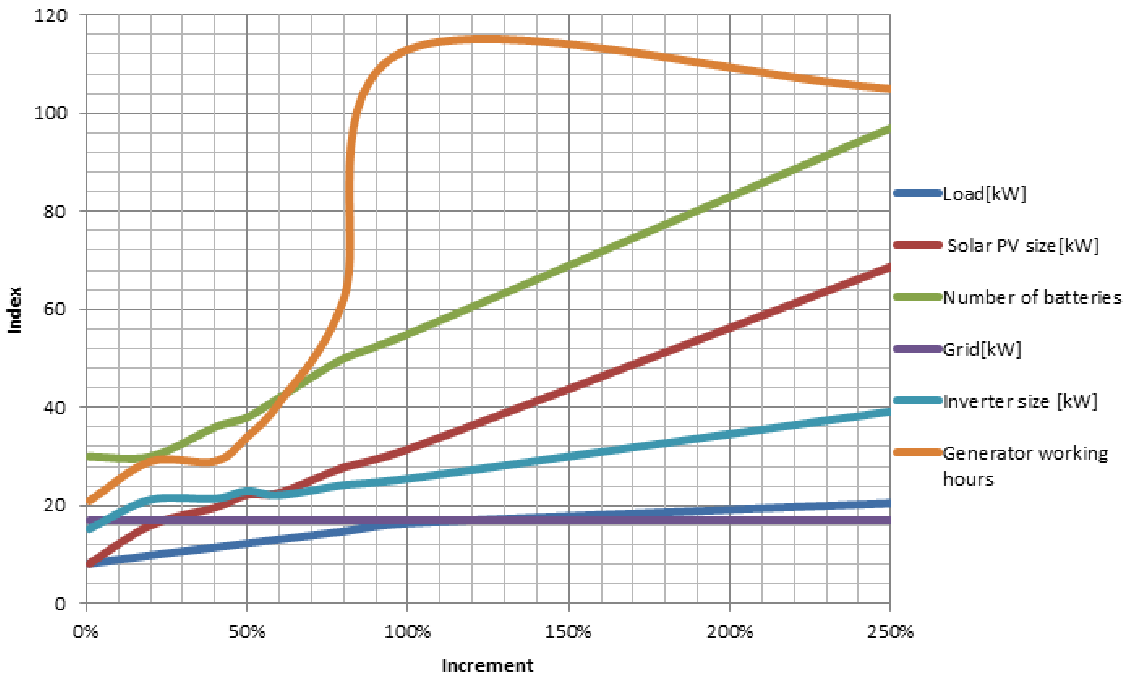

Figure 6.1: Load increment versus solar PV component

The figure 6.1 can be used by any user who needs to find the optimal size of solar PV components without performing modelling and simulations in residential houses, schools, health facilities and commercial areas. For example, the black and oblique line shown in figure 6.2 represents different size of PV components at load increment from 100% to 120%. The line hits the load curve and the grid line at 16kW and 17kW respectively. The same line hits the inverter's curve and PV array at 27kW and 32kW respectively, while the number of batteries is 58 and generator operating hours are 115. The same procedure can be applied at any value of load's increment where respective size of the system components can be read at the intersection of each component's curve and the drawn line. Note that the best optimal values by using this technic can be obtained by drawing a straight vertical line.

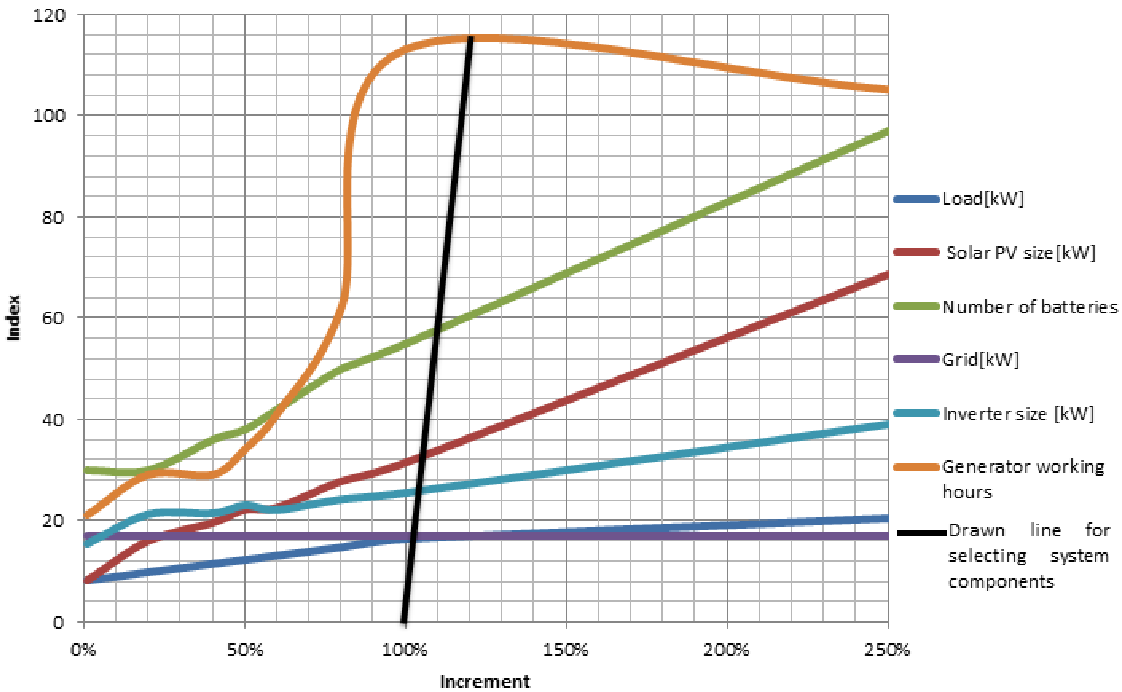

Figure 6.2: Load increment versus solar PV components at optimal values

Installation layout is generally considered as the tool for guiding the installer during project implementation. Two installation options proposed in this report differ from their equipments component; size of equipments and financial impact. Option one is used to support energy system for selected loads which need uninterruptable power supply.The system in option one is cheap, less complex, and easy to design and to implement. The only drawback is the tedious work required for separating the critical load from less critical load. The same schema can be used in any application where uninterruptable power supply for specific loads is a requirement. On the other hand, the schema shown in option two can be used either to sustain the existing large energy system or to make an island network in remote areas. It is complex and expensive system, but it presents advantage of supplying big load and being flexible to accommodate equipment in different locations.

The simulating tool, HOMER is recently preferred by many researchers who want to have an overview about technical and financial feasibility studies of different configurations of power sources. They are choosing HOMER because it is flexible and specialized in modeling mixtures of conventional power and renewable sources. Though HOMER can be used to simulate both reliability and sensitivity of mixed power systems, it has limitation to model advanced technical performances of mixed power system such as power system control and protection. The other limitation of using HOMER is the price to have a licensed version. Therefore, the users of simulating tool HOMER should use other simulating tools when control and protection of the system are required. .

During load profile creation AC load variations were taken arbitrary, 10% as possible variation between days because the hospital services includes emergencies activities are almost equally distributed across seven days per week during the year. But in reality each single moment AC load can vary depend both on the service going on and electrical medical and non electrical medical equipment used. In this report, 40% variation within time step was used in modelling to attenuate errors which can arise from the assumption made of considering 8.2kW as constant load of critical equipments. To be certain of 40% considered, analysis was performed to see how different parameters are affected by this decision. In other words, how each single technology respond to the selection of variation, or by selecting high or less percentage of variation and how economic parameters are affected. Figure 6.3 shows pattern of each parameter studied, where by increasing time step variation from zero percent, the AC load will slightly increase proportionally as percent goes high. In contrast, energy technologies itself respond to that by supplying different load in order to balance energy demand. Importantly, economical parameters are not affected by this small variation of energy use as illustrated by green cover which stands for levelised cost of electricity.

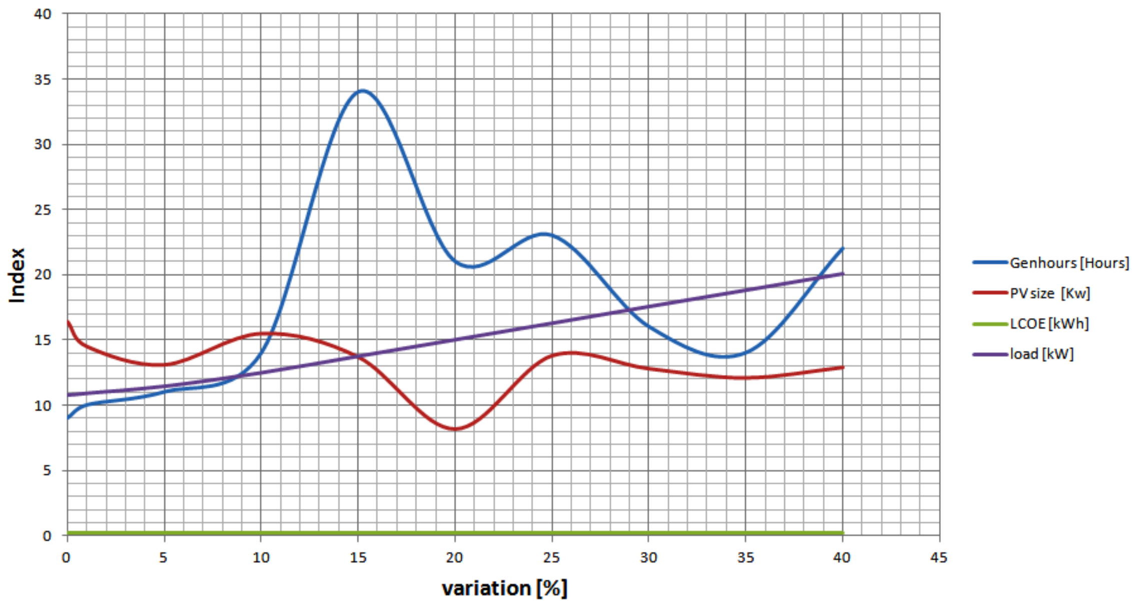

Figure 6.3: Load variation within time step

6.3 Sustainability

Concerning four possible power supply system configurations at Kolandoto Hospital obtained from modelling which are:

1st Configuration: *Grid, Solar PV, diesel generator, inverter and batteries*
2nd Configuration: *Grid, diesel generator, Inverter and batteries*
3rd Configuration: *Grid and diesel generator*

4thConfiguration: *Solar PV,Diesel generator,Grid and inverter*

It has been shown by table 5.7 that each configuration has a unique characteristics compared to the rest, in accordance with the objectives of this work, sustainability perspective is the leading factor in order to select the best option configuration design.In other words trade-off between social-economic and environmental benefits is adopted to validate the design and modelling outputs.

As detailed in the previous parts of this report, inpatients lives, workers and community at Kolandoto area suffer a lot because of insufficient and unstable source of power.The degree of power instability is clearly defined by a higher outage frequency which is estimated between one to two hours per day.Of course, it is not easy to quantitatively evaluate social negative impacts behind the power instability. But qualitative approach for each configurations obtained from the results can be adopted to selected good option that will enhance social benefits.

The indicator to measure the quality of power system configurations is the stability of electricity supply. The stability here means; electricity supply that can be able to meet peak power capacity demand; electricity supply that is available during health facility's working hours including night hours, electricity supply that has stable voltage, electricity supply that is affordable at reasonable cost and reliable.

Therefore among four configurations presented in table 5.7, the first configuration seems to fulfil said requirements than the rest, because the presence of Solar PV which has the capacity of 3.2kW and 8batteries will definitely mitigate outage problem especially in operation theatres where most of critical equipments are situated. In addition, the presence of inverter will stabilize the voltage for critical loads or total loads related to figure 5.2 and 5.3 respectively.

There are medical services benefits that considered as social benefits impacts/advantages directly associated to the selection of first configuration than choosing the rest.

By using the first configuration, higher risks or death rate occurred during surgical services will be minimized compared to existing power system. Sterilization procedures that can lead to disease complications will also be improved.Likewise having stable power at hospital generated by first configuration will allow medical services to be offered day and night hours and this will highly reduce the accumulation number of patients as well as will speed up the services. Maternal death happened due to birthing complication caused by outage of power source will be minimized. Security or safety in wards will also be enhanced.

Having stable power in health facilities, improves vaccine storage conditions which results in lower immunization failure rates and better immunization coverage. Therefore the first configuration stands as the best option among four, and fulfils the capability of supplying stable power and this will positively impacted the society of Kolandoto hospital.

Furthermore selection criteria for the best design are not only limited to social benefits impacts but also affordability, here means financial results should be considered.Key financial indicators that used to evaluate four configurations results are levelised cost and net present cost. Where figure 5.5,LCOE for possible power supply illustrates that first option which holds solar PV integrated in the current system with battery as backup system has less cost of electricity during the entire period of the system (25years) compared to others. In the same way, Net present costs resulted from simulations shows he same pattern as LCOE according to figure 5.6.

The LCOE and NPC results presented are not only basically affected by initial cost,operation and maintenance costs of the system, but also they are affected by other factors such as frequency of outage considered, discount rate and expected inflation rate.Precisely, the obtained LCOE and NPC results in this report are calculated based on the averaged discount rate and inflation rate as indicated by highlighted raw in table 6.1. However the results show that when discount and inflation rates increase at the same time as indicated by option 7 and 10 in the table 6.1, levelised cost of the electricity and net present cost ascend a little bit.The same if both discount rate and inflation rate fall down, levelised cost of electricity and net present cost do not decrease at all, confer option number 2 compared to 7.

Table 6.1: Discount and expected inflation rates sensitivity analysis

Option	Discount rate	Expected inflation rate	LCOE	NPC
1	14	0	0.44	221928.4
2	3.5	0	0.38	457772.4
3	7	0	0.4	340715.7
4	14	4.89	0.41	301925.2
5	3.5	4.89	0.35	771788.8
6	7	4.89	0.37	529685.1
7	14	5.1	0.41	306448.1
8	3.5	5.1	0.35	790919.5
9	7	5.1	0.37	540926.4
10	14	6.1	0.4	329582.1
11	3.5	6.1	0.35	890639.4
12	7	6.1	0.37	599174

Openly levelised cost of electricity and net present cost obtained have higher values, first because of the restriction of solar PV capacity to be integrated in the system, only 3.2kW and restriction to a maximum number of 8batteries because of limited funds.Second LCOE and NPC values are boosted by the higher cost of existing big diesel generator 36kW used in the simulations, which was not possible to consider another with less cost and less capacity to supply the demand of 8.2kW. To solve this problematic,simulation were executed without much restriction on solar PV capacity.The results prove that when solar PV capacity is increased up to 4.5kW with

35batteries, levelised cost of electricity and net present cost fall in the reasonable range with 0.18$ and around 260,000$ respectively. Consequently, without restrictions, first configuration selected and discussed above can be upgraded to the level of having 4.5kW from solar and 35 units of batteries when the investment is available.

Above social benefits and financial considerations which make the first configuration the best option, also it is clear in the figure 5.7 that the same first configuration stands for good position for less carbon emitters. The main reason for this carbon emissions difference is the effect of renewable energy fraction, where in the first configuration renewable energy grasps 6.4% of its power production, while the configuration considered as baseline condition (third) do not have green energies fraction and emits a lot of carbon emissions.

Besides carbon dioxide discrepancies for all four configuration of energy supply, figure 5.7 also illustrates the same pattern for other greenhouse gas emissions: CO, UHC, PM, SO_2,and NO_X.The presence of emissions in all design options are obviously from gird and the fossil fuel used, in this case diesel which has been counted at 2663.5grams of carbon per litter and other emissions are from grid factor emission where in Tanzania currently is 586grams of dioxide carbon per kWh.Therefore the differences in amount of emissions are directly proportional to operation hours of the generator and the use grid power.

7
Conclusion

The aim of this work was to investigate and evaluate ways solar PV could be used to meet power security in healthy facilities in Tanzania. And then after, propose a system that could sustain current electricity power supply at Kolandoto hospital.

Through modelling and optimization; results have shown that electrical production, emissions and cost of a hybridized system of solar PV-inverter-batteries-diesel generator-grid is the best solution among four feasible configurations. This system can be a solution for remote and urban areas of Tanzania where the reliability of the power grid is low. Hence, Kolandoto hospital's power failures as well as those of other health facilities, residential, schools and commercial areas would be alleviated by use of the first configuration and installation layouts presented in this work.

Schema considered in this report as option one that consists of 8.7kW of solar PV, hybrid inverter of 15.3kW and 30batteries of 245Ah, 12V all interconnected to the existing power system, has proven to decrease fuel dependency and its cost, to mitigate the cost of grid propagation and improve reliability of electricity from power grid at Kolandoto hospital. For other users whose power systems characteristics similar to that of Kolandoto hospital can use the figure 6.2 presented in this report to select optimal PV components. The environment impact associated to the proposed hybrid system is another factor that has supported the first configuration to be a best solution.

On the other hand, hybrid system that supplies total energy demand at Kolandoto hospital is found to be more cost effective in long run than hybridized system for supplying critical loads only. The installation layout proposed for critical loads has the economic advantages over the one proposed for total load. The major limitation found for total load was high investment required to meet total demand. However, all installation layouts can accommodate more components and can be expanded in the future.

Recommendations

Beyond the scope of this study there are uncovered works that could be important either to the other health facilities or to the energy system of Kolandoto hospital. The same future works can support the promotion of hybridized solar photovoltaic in order to decrease fuel dependency and its cost, or to mitigate the cost of grid propagation at the same time improving reliability of electricity from grid in developing countries. Therefore, the following recommendations are given:

1. To reduce the overall energy consumption by using energy efficiency devices, such as the replacement of incandescent and compact fluorescent light bulbs by LED light bulbs, the replacement of old electrical equipments by new ones in health facilities, and to automate the existing diesel generator in order to enhance back up system.
2. To evaluate the exploitation of solar thermal and how it can be combined with other power sources at Kolandoto hospital to reduce electricity required in heating system.
3. Regional grid regulations should be amended and allow grid interactive connection of solar power or other individual renewable generation sources into national grid.
4. Scientific approach for sizing solar equipments in hybridized systems needs further development.

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A
Appendix A

Table A.1: Inventory of critical loads at Kolandoto hospital

#	Items	Qty	Power (W)				Energy					
			Nominal rating	Maximum	Mean Operation	Total mean operation Power	Hours/Day	Hours/Night	Total Hours	Days/Week	Total Wh/week	Total Wh/Day
						Paediatric ward						
1	Light Tubes/ Reception	1	36		36	36	0.5	0.5	1	7	252	36
2	Light Tubes outdoor	3	36		36	108	0	1	1	7	756	108
3	Light Tubes indoor	13	36		36	468	0	1	1	7	3276	468
4	Energy Saver bulbs	4	18		18	72	0	1	1	7	504	72
5	Oxygen machine	1	322	224	322	322	1	0	1	7	2254	322
		Total			448	1006			5		7042	**1006**
						General ward						
1	Light Tube indoor/ Reception	1	36		36	36	0.5	0.5	1	7	252	36
2	Light Tubes outdoor	2	36		36	72	0	1	1	7	504	72
3	Light Tubes indoor	42	36		36	1512	0	1	1	7	10584	1512
		Total			108	1620			3		11340	**1620**
						Eye theater						
1	Light tubes indoor	10	36		36	360	1	0	1	5	1800	257.1
2	Light tubes outdoor	2	36		36	72	0	1	1	7	504	72
3	Energy Sarver bulb	6	18		18	108	1	0	1	5	540	77.1
4	Operation lights	1	150	147	150	150	0.3	0	0.3	2	75	10.7
7	Microscopy	1	45	44	45	45	1	0	1	2	90	12.9
9	Anaesthesia machine	1	280	54	75	75	1	0	1	2	150	21.4
Total					360	810			5.3		3159	**451.3**

#	Items	Qty	Power (W)				Energy					
			Nominal rating	Maximum	Mean Operation	Total mean operation Power	Hours/Day	Hours/Night	Total Hours	Days/Week	Total Wh/week	Total Wh/Day
General operation theatre												
1	Lighting tubes outdoor	5	36		36	180	0	1	1	7	1260	180
2	Lighting tubes indoor	23	36		36	828	0.5	0.5	1	7	5796	828
3	Energy saver bulbs	3	18		18	54	0.5	0.5	1	7	378	54
4	Operation lights small room	1	300		300	300	1	0	1	0.1	21	3
5	Operation lights big	1	400		400	400	1	0	1	7	2800	400
7	Operation bed big	1	240	191	240	240	1	0	1	7	1680	240
7	Operation bed small	1	240	194	240	240	1	0	1	0.1	16.8	2.4
8	Electro surgery machine small	1	1000		150	150	1	0	1	0.1	10.5	1.5
9	Electro surgery machine big	1	1000	117	150	150	1	0	1	7	1050	150
10	Suction machine	1	220		220	220	0.3	0	0.3	2	110	15.7
14	Anaesthesia machine	1	320	124	150	150	1	0	1	7	1050	150
Total					1940	2912			10.3		14172.3	**2024.6**
Maternity theater												
1	Light tubes indoor	6	36		36	216	0.5	0.5	1	7	1512	216
2	Light tubes outdoor	2	36		36	72	0	1	1	7	504	72
3	Operation light	1	300		300	300	0.5	0	0.5	7	1050	150
4	Operation bed	1	240		240	240	0.5	0	0.5	7	840	120
5	Suction machine	1	90	119	140	140	0.3	0	0.3	1	35	5
6	Electro surgery machine	1	600	35	90	90	0.5	0	0.5	7	315	45
7	Anaesthesia machine	1	320	103	150	150	0.5	0	0.5	7	525	75
Total					992	1208			4.3		4781	**683**

#	Items	Qty	Power (W)				Energy					
			Nominal rating	Maximum	Mean operation	Total mean operation Power	Hours/Day	Hours/Night	Total Hours	Days/Week	Total Wh/week	Total Wh/Day
Maternity ward												
1	Light tubes indoor	7	36		36	252	0	1	1	7	1764	252
2	Light tubes outdoor	1	36		36	36	0	1	1	7	252	36
3	Energy saver bulbs	8	18		18	144	0	1	1	7	1008	144
5	Suction machine (1)	1	90	132	150	150	0.3	0	0.3	0.1	2.6	0.4
6	Suction machine (2)	1	90	120	150	150	0	0	0	7	0	0
7	Baby warm air machine (1)	1	800	567	800	800	0.5	0	0.5	7	2800	400
8	Baby warm air machine (2)	1	800	615	800	800	1	0	1	7	5600	800
9	Oxygen machine	1		454	500	500	0.3	0	0.3	7	875	125
		Total			2490	2832			5		12301.6	**1757.4**
Private ward												
1	Light tubes indoor	15	36		36	540	0	1	1	7	3780	540
2	Light tubes indoor	1	36		36	36	0.5	0.5	1	7	252	36
3	Light tubes outdoor	2	36		36	72	0	1	1	7	504	72
4	Energy saver bulbs	1	18		18	18	0	1	1	7	126	18
Total					126	666			4		4662	**666**
Overall total energy [Wh/day]					8208.3							
Overall total instantaneous Power [W]					11054							

B
Appendix B

Table B.1: Inventory of electrical equipment at Kolandoto hospital

#	Items	Qty	Power (W)				Energy					
			Name plate	Measured value								
			Nominal rating	Maximum	Mean Operation	Total Mean Operation	Hours/Day	Hours/Night	Total Hours	Days/Week	Total Wh/week	Total Wh/Day
X-Ray & Ultrasound Unit												
1,0	Light tubes indoor	3,0	36,0		36,0	108,0	9,0	0,0	9,0	7,0	6804,0	972,0
2,0	Energy saver bulbs indoor	5,0	18,0		18,0	90,0	1,0	0,0	1,0	7,0	630,0	90,0
3,0	Red small bulbs	3,0	5,0		5,0	15,0	1,0	0,0	1,0	5,0	75,0	10,7
4,0	Elevator	1,0		1206,0	1200,0	1200,0	5,0	0,0	5,0	5,0	30000,0	4285,7
5,0	X-Ray Machine	1,0	700,0	671,0	612,0	612,0	5,0	0,0	5,0	5,0	15300,0	2185,7
6,0	Diagnostic Ultrasound system	1,0	800,0	380,0	380,0	380,0	7,0	0,0	7,0	3,0	7980,0	1140,0
7,0	Electric Fan	1,0	60,0	62,0	57,0	57,0	0,5	0,0	0,5	5,0	142,5	20,4
Total					2308,0	2462,0	28,5	0,0	28,5	37,0	60931,5	**8704,5**
Pharmacy												
1,0	Light tubes indoor	2,0	36,0		36,0	72,0	12,0	12,0	24,0	7,0	12096,0	1728,0
2,0	Light tubes outdoor	7,0	36,0		36,0	252,0	0,0	12,0	12,0	7,0	21168,0	3024,0
3,0	Energy Saver bulbs	3,0	18,0		18,0	54,0	0,0	0,5	0,5	7,0	189,0	27,0
4,0	Air conditionner	1,0	1348,0	1045,0	1001,0	1001,0	12,0	12,0	24,0	7,0	168168,0	24024,0
5,0	Fridge	1,0	118,0	267,0	107,0	107,0	12,0	12,0	24,0	7,0	17976,0	2568,0
Total					1198,0	1486,0	36,0	48,5	84,5		219597,0	**31371,0**
Laundry												
1,0	Light Tubes indoor	2,0	36,0		36,0	72,0	12,0	0,0	12,0	6,0	5184,0	740,6
2,0	Energy Saver bulbs	2,0	18,0		18,0	36,0	0,0	0,3	0,3	6,0	54,0	7,7
3,0	Small Bulbles	3,0	5,0		5,0	15,0	8,0	0,0	8,0	6,0	720,0	102,9
4,0	Laundry machine	2,0	12800,0		12800,0	25600,0	8,0	0,0	8,0	6,0	1228800,0	175542,9
Total					12859,0	25723,0	28,0	0,3	28,3		1234758,0	**176394,0**

#	Items	Qty	Power (W)				Energy					
			Name plate	Measured value								
			Nominal rating	Maximum	Mean Operation	Total Mean Operation	Hours/Day	Hours/Night	Total Hours	Days/Week	Total Wh/week	Total Wh/Day
						Dental Unit						
1,0	Light Tubes indoor	2,0	36,0		36,0	72,0	0,5	0,0	0,5	5,0	180,0	25,7
2,0	Light Tubes indoor comp	1,0	36,0		36,0	36,0	8,0	0,0	8,0	5,0	1440,0	205,7
3,0	Special tube	1,0	60,0		60,0	60,0	0,5	0,0	0,5	1,0	30,0	4,3
4,0	Flex integral machine	1,0	2000,0		2000,0	2000,0	1,0	0,0	1,0	5,0	10000,0	1428,6
5,0	Stelirizer machine	1,0		2065,0	2045,0	2045,0	1,0	0,0	1,0	5,0	10225,0	1460,7
6,0	Compressor	1,0			1132,0	1132,0	1,0	0,0	1,0	5,0	5660,0	808,6
7,0	Pump	1,0		1266,0	1182,0	1182,0	1,0	0,0	1,0	5,0	5910,0	844,3
	Total				6491,0	6527,0	13,0	0,0	13,0		33445,0	**4777,9**
						Infusion Unit						
1,0	Light Tubes indoor autoclave	2,0	36,0		36,0	72,0	8,0	1,0	9,0	5,0	3240,0	462,9
1,0	Light Tubes indoor	4,0	36,0		36,0	144,0	0,0	2,0	2,0	5,0	1440,0	205,7
2,0	Iden 510s Autoclave (1)	1,0	7000,0		7000,0	7000,0	2,0	0,0	2,0	5,0	70000,0	10000,0
3,0	Autoclave boiler (2)	1,0	4500,0		4500,0	4500,0	6,0	0,0	6,0	5,0	135000,0	19285,7
4,0	Riverse Osmosis machine	1,0	370,0	364,0	359,0	359,0	4,0	0,0	4,0	5,0	7180,0	1025,7
4,0	Diaphragm vacuum pump	1,0	345,0	174,0	170,0	170,0	1,0	0,0	1,0	5,0	850,0	121,4
	Total				12101,0	12245,0	21,0	3,0	24,0		217710,0	**31101,4**
						Physiotherapy						
1,0	light Tubes indoor	1,0	36,0		36,0	36,0	1,0	0,0	1,0	5,0	180,0	25,7
2,0	Cast cutter	1,0	330,0	243,0	235,0	235,0	1,0	0,0	1,0	5,0	1175,0	167,9
	Total				271,0	271,0	2,0	0,0	2,0		1355,0	**193,6**

#	Items	Qty	Power (W)				Energy					
			Name plate	Measured value								
			Nominal rating	Maximum	Mean Operation	Total Mean Operation	Hours/Day	Hours/Night	Total Hours	Days/Week	Total Wh/week	Total Wh/Day
Family Planning												
1,0	Light Tubes indoor	2,0	36,0		36,0	72,0	0,0	1,0	1,0	4,0	288,0	41,1
2,0	Light Tubes outdoor	4,0	36,0		36,0	144,0	0,0	12,0	12,0	7,0	12096,0	1728,0
3,0	Energy Saver bulbs	2,0	18,0		18,0	36,0	0,0	0,3	0,3	1,0	9,0	1,3
4,0	Water heater/boiler	1,0	1500,0	1653,0	1618,0	1618,0	1,0	0,0	1,0	1,0	1618,0	231,1
5,0	Electric fan	2,0	75,0		75,0	150,0	1,0	0,0	1,0	4,0	600,0	85,7
6,0	Working Lamps	2,0	60,0	57,0	54,0	108,0	1,0	0,0	1,0	1,0	108,0	15,4
Total					1837,0	2128,0	3,0	13,3	16,3		14719,0	**2102,7**
Mental Health Services and Nursing Section Supervisor												
1,0	Light Tubes indoor	1,0	36,0		36,0	36,0	0,0	12,0	12,0	5,0	2160,0	308,6
2,0	Light Tubes outdoor	1,0	36,0		36,0	36,0	0,0	12,0	12,0	7,0	3024,0	432,0
3,0	Energy Saver bulbs	3,0	18,0		18,0	54,0	0,0	0,3	0,3	5,0	67,5	9,6
Total					90,0	126,0	0,0	24,3	24,3		5251,5	**750,2**
Tuberculosis and leprosy												
1,0	Light Tubes indoor	1,0	36,0		36,0	36,0	8,0	0,0	8,0	5,0	1440,0	205,7
2,0	Light Tubes outdoor	2,0	36,0		36,0	72,0	0,0	12,0	12,0	7,0	6048,0	864,0
Total					72,0	108,0	8,0	12,0	20,0		7488,0	**1069,7**

#	Items	Qty	Power (W)				Energy					
			Name plate	Measured value			Hours/Day	Hours/Night	Total Hours	Days/Week	Total Wh/week	Total Wh/Day
			Nominal rating	Maximum	Mean Operation	Total Mean Operation						
Care treatment center												
1,0	Light Tubes indoor	7,0	36,0		36,0	252,0	8,0	0,0	8,0	5,0	10080,0	1440,0
2,0	Light Tubes outdoor	2,0	36,0		36,0	72,0	0,0	12,0	12,0	7,0	6048,0	864,0
3,0	Energy Saver bulbs	2,0	18,0		18,0	36,0	0,0	0,3	0,3	5,0	45,0	6,4
4,0	Printer machine	1,0	500,0	739,0	369,0	369,0	1,0	0,0	1,0	2,0	738,0	105,4
5,0	Computer (1)	1,0	100,0	92,0	81,0	81,0	6,0	0,0	6,0	2,0	972,0	138,9
6,0	Computer (2)	1,0	120,0	101,0	82,0	82,0	6,0	0,0	6,0	2,0	984,0	140,6
7,0	TV	1,0	100,0	83,0	62,0	62,0	8,0	0,0	8,0	5,0	2480,0	354,3
Total					684,0	954,0	29,0	12,3	41,3		21347,0	**3049,6**
Paediatric Ward												
1,0	Light Tubes/ Reception	1,0	36,0		36,0	36,0	12,0	12,0	24,0	7,0	6048,0	864,0
2,0	Light Tubes outdoor	3,0	36,0		36,0	108,0	0,0	12,0	12,0	7,0	9072,0	1296,0
3,0	Light Tubes indoor	13,0	36,0		36,0	468,0	0,0	12,0	12,0	7,0	39312,0	5616,0
4,0	Energy Saver bulbs	4,0	18,0		18,0	72,0	0,0	1,0	1,0	7,0	504,0	72,0
5,0	Oxygen machine	1,0	322,0	224,0	220,0	220,0	2,3	0,0	2,3	7,0	3465,0	495,0
Total					346,0	904,0	14,3	37,0	51,3		58401,0	**8343,0**
Mortuary												
1,0	light Tubes indoor	3,0	36,0		36,0	108,0	12,0	12,0	24,0	7,0	18144,0	2592,0
2,0	light Tubes outdoor	9,0	36,0		36,0	324,0	0,0	12,0	12,0	7,0	27216,0	3888,0
3,0	Fridge	1,0		759,0	600,0	600,0	12,0	12,0	24,0	7,0	100800,0	14400,0
Total					672,0	1032,0	24,0	36,0	60,0		146160,0	**20880,0**
General ward												
1,0	Light Tube indoor/ Reception	1,0	36,0		36,0	36,0	12,0	12,0	24,0	7,0	6048,0	864,0
2,0	Light Tubes outdoor	2,0	36,0		36,0	72,0	0,0	12,0	12,0	7,0	6048,0	864,0
3,0	Light Tubes indoor	42,0	36,0		36,0	1512,0	0,0	12,0	12,0	7,0	127008,0	18144,0
4,0	suction machine(male +female)	2,0		60,0	59,0	118,0	0,0	0,0	0,0	7,0	0,0	0,0
Total					167,0	1738,0	12,0	36,0	48,0		139104,0	**19872,0**

#	Items	Qty	Power (W)				Energy					
			Name plate	Measured value			Hours/Day	Hours/Night	Total Hours	Days/Week	Total Wh/week	Total Wh/Day
			Nominal rating	Maximum	Mean Operation	Total Mean Operation						
2,0	Light Tubes outdor	5,0	36,0		36,0	180,0	0,0	12,0	12,0	7,0	15120,0	2160,0
3,0	Energy Saver bulbs	4,0	18,0		18,0	72,0	0,0	0,5	0,5	5,0	180,0	25,7
4,0	Dometic Fridge	1,0	300,0	132,0	126,0	126,0	12,0	12,0	24,0	7,0	21168,0	3024,0
5,0	Boiler autoclave	1,0	2000,0	2126,0	2110,0	2110,0	0,2	0,0	0,2	5,0	1582,5	226,1
6,0	Portable lamp	1,0	3,0	4,0	4,0	4,0	1,0	0,0	1,0	5,0	20,0	2,9
7,0	Fridge (Electrolux)	1,0	85,0	93,0	86,0	86,0	12,0	12,0	24,0	7,0	14448,0	2064,0
8,0	Kettle	1,0	1800,0	1451,0	1429,0	1429,0	0,5	0,0	0,5	1,0	714,5	102,1
Total					3845,0	4259,0	26,7	36,5	63,2		54493,0	**7784,7**
Quantines /Social hall												
1,0	light Tubes indoor	3,0	36,0		36,0	108,0	12,0	12,0	24,0	7,0	18144,0	2592,0
2,0	light Tubes indoor	8,0	36,0		36,0	288,0	0,0	4,0	4,0	7,0	8064,0	1152,0
3,0	Light Tubes outdoor	7,0	36,0		36,0	252,0	0,0	12,0	12,0	7,0	21168,0	3024,0
4,0	Energy sarver Bulbs	2,0	18,0		18,0	36,0	0,0	12,0	12,0	7,0	3024,0	432,0
5,0	Energy sarver bulbs	8,0	18,0		18,0	144,0	0,0	4,0	4,0	7,0	4032,0	576,0
6,0	Fridge	1,0		534,0	478,0	478,0	12,0	12,0	24,0	7,0	80304,0	11472,0
Total					622,0	1306,0	24,0	56,0	80,0		134736,0	**19248,0**
Security Gate												
1,0	Light Tubes outdoor	3,0	36,0		36,0	108,0	0,0	12,0	12,0	7,0	9072,0	1296,0
2,0	Light Tubes indoor	2,0	36,0		36,0	72,0	0,0	12,0	12,0	7,0	6048,0	864,0
Total					36,0	180,0	0,0	24,0	24,0		15120,0	**2160,0**

#	Items	Qty	Power (W)				Energy					
			Name plate	Measured value			Hours/Day	Hours/Night	Total Hours	Days/Week	Total Wh/week	Total Wh/Day
			Nominal rating	Maximum	Mean Operation	Total Mean Operation						
Staff Hostel												
1,0	Light Tubes	2,0	36,0		36,0	72,0	0,0	12,0	12,0	7,0	6048,0	864,0
2,0	Energy Saver bulbs indoor	2,0	18,0		18,0	36,0	0,0	12,0	12,0	7,0	3024,0	432,0
3,0	Energy sarver bulbs outdoor	1,0	18,0		18,0	18,0	0,0	12,0	12,0	7,0	1512,0	216,0
4,0	Television	3,0	65,0		65,0	195,0	2,0	4,0	6,0	7,0	8190,0	1170,0
5,0	Iron	1,0	2000,0		2000,0	2000,0	0,3	0,0	0,3	7,0	3500,0	500,0
6,0	Radio	3,0	40,0		40,0	120,0	2,0	5,0	7,0	7,0	5880,0	840,0
7,0	Pressure cooker	1,0	2000,0		2000,0	2000,0	1,5	2,0	3,5	7,0	49000,0	7000,0
	Total				4177,0	4441,0	5,8	47,0	52,8		77154,0	**11022,0**
Students hostel												
1,0	Light Tubes outdoor	5,0	36,0		36,0	180,0	0,0	12,0	12,0	7,0	15120,0	2160,0
2,0	Light Tubes indoor	22,0	36,0		36,0	792,0	0,0	12,0	12,0	7,0	66528,0	9504,0
3,0	Light Tubes indoor	2,0	36,0		36,0	72,0	12,0	12,0	24,0	7,0	12096,0	1728,0
4,0	Energy sarver bulbs	3,0	18,0		18,0	54,0	0,0	12,0	12,0	7,0	4536,0	648,0
	Total				126,0	1098,0	12,0	48,0	60,0		98280,0	**14040,0**
Water Pump house												
1,0	light Tubes outdoor	4,0	36,0		36,0	144,0	0,0	12,0	12,0	7,0	12096,0	1728,0
2,0	light Tubes indoor	1,0	36,0		36,0	36,0	0,0	12,0	12,0	7,0	3024,0	432,0
3,0	Energy sarver Bulbs	3,0	18,0		18,0	54,0	12,0	12,0	24,0	7,0	9072,0	1296,0
4,0	Water pump	1,0	5500,0		5500,0	5500,0	12,0	4,0	16,0	7,0	616000,0	88000,0
	Total				5590,0	5734,0	24,0	40,0	64,0		640192,0	**91456,0**
Power house												
1,0	light Tubes outdoor	3,0	36,0		36,0	108,0	12,0	12,0	24,0	7,0	18144,0	2592,0
2,0	light Tubes indoor	2,0	36,0		36,0	72,0	0,0	12,0	12,0	7,0	6048,0	864,0
3,0	Energy sarver bulb	1,0	18,0		18,0	18,0	0,0	1,0	1,0	7,0	126,0	18,0
	Total				90,0	198,0	12,0	25,0	37,0		24318,0	**3474,0**

#	Items	Qty	Power (W)				Energy					
			Name plate	Measured value			Hours/Day	Hours/Night	Total Hours	Days/Week	Total Wh/week	Total Wh/Day
			Nominal rating	Maximum	Mean Operation	Total Mean Operation						
Church												
1,0	light Tubes indoor	5,0	36,0		36,0	180,0	2,0	0,0	2,0	7,0	2520,0	360,0
2,0	light Tubes outdoor	7,0	36,0		36,0	252,0	12,0	0,0	12,0	7,0	21168,0	3024,0
3,0	Energy sarver Bulb	9,0	18,0		18,0	162,0	2,0	0,0	2,0	7,0	2268,0	324,0
Total					90,0	594,0	16,0	0,0	16,0		25956,0	**3708,0**
Church office												
1,0	light Tubes outdoor	4,0	36,0		36,0	144,0	0,0	12,0	12,0	7,0	12096,0	1728,0
2,0	light Tubes indoor	3,0	36,0		36,0	108,0	8,0	0,0	8,0	7,0	6048,0	864,0
3,0	Energy sarver Bulb	1,0	18,0		18,0	18,0	0,0	1,0	1,0	7,0	126,0	18,0
Total					90,0	270,0	8,0	13,0	21,0		18270,0	**2610,0**
Old- Canteen												
1,0	light Tubes outdoor	1,0			36,0	36,0	0,0	12,0	12,0	7,0	3024,0	432,0
2,0	light Tubes indoor	1,0			36,0	36,0	0,0	1,0	1,0	5,0	180,0	25,7
Total					36,0	36,0	0,0	13,0	13,0		3204,0	**457,7**
Store house												
1,0	light Tubes indoor	4,0	36,0		36,0	144,0	12,0	0,0	12,0	5,0	8640,0	1234,3
2,0	light Tubes indoor	1,0	36,0		36,0	36,0	12,0	12,0	24,0	7,0	6048,0	864,0
3,0	light Tubes outdoor	1,0	36,0		36,0	36,0	0,0	12,0	12,0	7,0	3024,0	432,0
4,0	Energy sarver Bulb outdoor	1,0	18,0		18,0	18,0	0,0	12,0	12,0	7,0	1512,0	216,0
Total					126,0	234,0	24,0	36,0	60,0		19224,0	**2746,3**

#	Items	Qty	Power (W)				Energy					
			Name plate	Measured value								
			Nominal rating	Maximum	Mean Operation	Total Mean Operation	Hours/Day	Hours/Night	Total Hours	Days/Week	Total Wh/week	Total Wh/Day
Admistration Office												
1,0	light tubes outdoor	9,0	36,0		36,0	324,0	0,0	12,0	12,0	7,0	27216,0	3888,0
2,0	light tubes indoor	15,0	36,0		36,0	540,0	8,0	0,0	8,0	5,0	21600,0	3085,7
3,0	Energy sarver bulbs	5,0	18,0		18,0	90,0	1,0	0,0	1,0	5,0	450,0	64,3
4,0	Computer (1) (Accountant)	1,0	120,0		74,0	74,0	8,0	0,0	8,0	5,0	2960,0	422,9
5,0	Computer (2) +Fan (Accountant)	1,0	200,0	197,0	166,0	166,0	8,0	0,0	8,0	5,0	6640,0	948,6
6,0	Computer (3) Secretary	1,0	220,0	202,0	171,0	171,0	8,0	0,0	8,0	5,0	6840,0	977,1
7,0	Computer (4) Planning	1,0	60,0	57,0	35,0	35,0	1,0	0,0	1,0	5,0	175,0	25,0
8,0	Computer (5) Plannig	1,0	150,0	139,0	102,0	102,0	8,0	0,0	8,0	5,0	4080,0	582,9
9,0	Fan (in charge office)	2,0	75,0	51,0	42,0	84,0	4,0	0,0	4,0	5,0	1680,0	240,0
10,0	Printer	1,0	450,0	421,0	380,0	380,0	1,0	0,0	1,0	5,0	1900,0	271,4
11,0	Scanner	1,0		23,0	9,0	9,0	0,3	0,0	0,3	5,0	11,3	1,6
12,0	Photocopy Machine	1,0		150,0	141,0	141,0	1,0	0,0	1,0	5,0	705,0	100,7
13,0	Hibrid system (landline phone)	1,0			13,0	13,0	12,0	12,0	24,0	7,0	2184,0	312,0
14,0	Hot plate/ Cooker	1,0	2200,0		2200,0	2200,0	2,0	0,0	2,0	5,0	22000,0	3142,9
Total					3423,0	4329,0	62,3	24,0	86,3		98441,3	**14063,0**
OPD												
1,0	Light Tubes indoor	12,0	36,0		36,0	432,0	12,0	0,0	12,0	7,0	36288,0	5184,0
2,0	Light Tubes indoor	7,0	36,0		36,0	252,0	8,0	0,0	8,0	7,0	14112,0	2016,0
3,0	Light Tubes outdoor	8,0	36,0		36,0	288,0	0,0	12,0	12,0	7,0	24192,0	3456,0
4,0	Energy saver Bulb	1,0	18,0		18,0	18,0	12,0	0,0	12,0	7,0	1512,0	216,0
Total					126,0	990,0	32,0	12,0	44,0		76104,0	**10872,0**

#	Items	Qty	Power (W)				Energy					
			Name plate	Measured value			Hours/Day	Hours/Night	Total Hours	Days/Week	Total Wh/week	Total Wh/Day
			Nominal rating	Maximum	Mean Operation	Total Mean Operation						
Eye theater												
1,0	Light tubes indoor	10,0	36,0		36,0	360,0	8,0	0,0	8,0	5,0	14400,0	2057,1
2,0	Light tubes outdoor	2,0	36,0		36,0	72,0	0,0	12,0	12,0	7,0	6048,0	864,0
3,0	Energy Sarver bulb	6,0	18,0		18,0	108,0	2,0	0,0	2,0	5,0	1080,0	154,3
4,0	Operation lights	1,0	150,0	147,0	147,0	147,0	0,3	0,0	0,3	2,0	73,5	10,5
5,0	Air conditioner	1,0	1320,0		1320,0	1320,0	8,0	0,0	8,0	2,0	21120,0	3017,1
6,0	Boiler	1,0			1922,0	1922,0	2,0	0,0	2,0	2,0	7688,0	1098,3
7,0	Microscopy	1,0		44,0	40,0	40,0	6,0	0,0	6,0	2,0	480,0	68,6
8,0	Television	1,0		37,0	36,0	36,0	8,0	0,0	8,0	2,0	576,0	82,3
9,0	Anestesia Machine	1,0	280,0	54,0	52,0	52,0	1,0	0,0	1,0	2,0	104,0	14,9
10,0	Fan	1,0	45,0		45,0	45,0	8,0	0,0	8,0	2,0	720,0	102,9
Total					3652,0	4102,0	43,3	12,0	55,3		52289,5	**7469,9**
Eye ward/ Audi												
1,0	Light Tubes indoor	19,0	36,0		36,0	684,0	2,0	12,0	14,0	7,0	67032,0	9576,0
2,0	Light Tubes outdoor	1,0	36,0		36,0	36,0	0,0	12,0	12,0	7,0	3024,0	432,0
3,0	Energy Saver bulb indoor	16,0	18,0		18,0	288,0	1,0	12,0	13,0	7,0	26208,0	3744,0
4,0	Energy Saver bulb outdoor	1,0	18,0		18,0	18,0	0,0	12,0	12,0	7,0	1512,0	216,0
5,0	Slip lamp (1)	1,0		1,0	1,0	1,0	0,0	0,0	0,0	5,0	0,0	0,0
6,0	Slip lamp (2)	1,0		38,0	38,0	38,0	2,0	0,0	2,0	5,0	380,0	54,3
7,0	Lenso-meter	1,0		22,0	22,0	22,0	0,5	0,0	0,5	5,0	55,0	7,9
8,0	Boiler (1)	1,0		1650,0	1620,0	1620,0	3,0	0,0	3,0	7,0	34020,0	4860,0
9,0	Grinding Machine	1,0		103,0	95,0	95,0	0,0	0,0	0,0	7,0	0,0	0,0
10,0	Television	1,0		82,0	80,0	80,0	12,0	3,0	15,0	7,0	8400,0	1200,0
11,0	Boiler (2)	1,0		1631,0	1574,0	1574,0	0,3	0,0	0,3	4,0	1574,0	224,9
Total					3538,0	4456,0	20,8	51,0	71,8		142205,0	**20315,0**

#	Items	Qty	Power (W)				Energy					
			Name plate	Measured value			Hours/Day	Hours/Night	Total Hours	Days/Week	Total Wh/week	Total Wh/Day
			Nominal rating	Maximum	Mean Operation	Total Mean Operation						
Labratory												
1,0	Light Tubes outdoor	1,0	36,0		36,0	36,0	0,0	12,0	12,0	7,0	3024,0	432,0
2,0	Light Tubes indoor	5,0	36,0		36,0	180,0	12,0	12,0	24,0	7,0	30240,0	4320,0
3,0	Light Tubes indoor	6,0	36,0		36,0	216,0	8,0	0,0	8,0	7,0	12096,0	1728,0
4,0	Energy saver bulb indoor	1,0	18,0		18,0	18,0	1,0	0,0	1,0	7,0	126,0	18,0
5,0	Energy saver bulb	2,0	18,0		18,0	36,0	0,5	0,0	0,5	7,0	126,0	18,0
6,0	Fridge (1)	1,0	180,0	389,0	107,0	107,0	12,0	12,0	24,0	7,0	17976,0	2568,0
7,0	Centrifuge machine	1,0		127,0	100,0	100,0	10,0	0,0	10,0	7,0	7000,0	1000,0
8,0	Screen Master	1,0	150,0	78,0	72,0	72,0	3,0	0,0	3,0	7,0	1512,0	216,0
9,0	Pima Machine (Beads)	1,0		60,0	51,0	51,0	2,5	0,0	2,5	7,0	892,5	127,5
10,0	Fridge (2)	1,0		161,0	120,0	120,0	12,0	12,0	24,0	7,0	20160,0	2880,0
11,0	Microscope	1,0	20,0	18,0	7,0	7,0	9,0	0,0	9,0	7,0	441,0	63,0
12,0	Hot air Oven	1,0	550,0	512,0	501,0	501,0	1,0	0,0	1,0	7,0	3507,0	501,0
13,0	Air conditionning	2,0	980,0	1075,0	1051,0	2102,0	12,0	12,0	24,0	7,0	353136,0	50448,0
14,0	Fridge (3)	1,0	180,0	195,0	132,0	132,0	0,0	0,0	0,0	7,0	0,0	0,0
15,0	Micro 60 OT	1,0	65,0	104,0	62,0	62,0	12,0	0,0	12,0	7,0	5208,0	744,0
16,0	Roller Mixer	1,0		19,0	18,0	18,0	4,0	0,0	4,0	7,0	504,0	72,0
15,0	Incubater automatic	1,0	500,0	506,0	366,0	366,0	0,0	0,0	0,0	7,0	0,0	0,0
16,0	Sysmex XP 300	1,0	200,0	196,0	155,0	155,0	12,0	0,0	12,0	7,0	13020,0	1860,0
Total					2886,0	4124,0	111,0	60,0	171,0		468968,5	**66995,5**
CSR / Center Sterilisation Unit												
1,0	Light tubes indoor	4,0	36,0		36,0	144,0	8,0	0,0	8,0	5,0	5760,0	822,9
2,0	Electric Pump	1,0	550,0	418,0	414,0	414,0	2,0	0,0	2,0	2,0	1656,0	236,6
3,0	Boiler	1,0		181,0	181,0	181,0	7,0	0,0	7,0	4,0	5068,0	724,0
4,0	Electric boiler	1,0	18000,0		18000,0	18000,0	2,0	0,0	2,0	5,0	180000,0	25714,3
Total					18631,0	18739,0	19,0	0,0	19,0		192484,0	**27497,7**

#	Items	Qty	Power (W)				Energy					
			Name plate	Measured value			Hours/Day	Hours/Night	Total Hours	Days/Week	Total Wh/week	Total Wh/Day
			Nominal rating	Maximum	Mean Operation	Total Mean Operation						
General Operation Theater												
1,0	Lighting tubes outdoor	5,0	36,0		36,0	180,0	0,0	10,0	10,0	7,0	12600,0	1800,0
2,0	Lighting tubes indoor	23,0	36,0		36,0	828,0	12,0	4,0	16,0	7,0	92736,0	13248,0
3,0	Energy saver bulbs	3,0	18,0		18,0	54,0	0,5	0,5	1,0	7,0	378,0	54,0
4,0	Operation lights small room	1,0	300,0		300,0	300,0	1,5	0,0	1,5	0,1	31,5	4,5
5,0	Operation lights big	1,0	400,0		400,0	400,0	1,5	0,0	1,5	7,0	4200,0	600,0
6,0	Operation bed small room	1,0	240,0	191,0	186,0	186,0	1,5	0,0	1,5	0,1	19,5	2,8
7,0	Operation bed big	1,0	240,0	191,0	186,0	186,0	1,5	0,0	1,5	7,0	1953,0	279,0
8,0	Electro surgery machine small	1,0	1000,0		1000,0	1000,0	1,5	0,0	1,5	0,1	105,0	15,0
9,0	Electro surgery machine big	1,0	1000,0	117,0	103,0	103,0	1,5	0,0	1,5	7,0	1081,5	154,5
10,0	Suction machine	1,0	220,0		220,0	220,0	0,3	0,0	0,3	2,0	110,0	15,7
11,0	Air conditionning small room	1,0			1500,0	1500,0	10,0	0,0	10,0	0,1	1050,0	150,0
12,0	Air conditionning	1,0			1500,0	1500,0	10,0	0,0	10,0	7,0	105000,0	15000,0
13,0	Anestesia machine small room	1,0	320,0	124,0	117,0	117,0	1,5	0,0	1,5	0,1	12,3	1,8
14,0	Anestesia machine	1,0	320,0	124,0	117,0	117,0	1,5	0,0	1,5	7,0	1228,5	175,5
15,0	Steriliser	1,0		450,0	448,0	448,0	1,3	0,0	1,3	7,0	3920,0	560,0
16,0	Rapid steriliser	1,0		1824,0	1810,0	1810,0	0,5	0,0	0,5	7,0	6335,0	905,0
17,0	Electic teakettle	1,0	2000,0		2000,0	2000,0	1,0	0,0	1,0	7,0	14000,0	2000,0
Total					9977,0	10949,0	47,5	14,5	62,0		244760,3	**34965,8**

#	Items	Qty	Power (W)				Energy					
			Name plate	Measured value			Hours/Day	Hours/Night	Total Hours	Days/Week	Total Wh/week	Total Wh/Day
			Nominal rating	Maximum	Mean Operation	Total Mean Operation						
Maternity theater												
1,0	Light tubes indoor	6,0	36,0		36,0	216,0	6,0	2,0	8,0	7,0	12096,0	1728,0
2,0	Light tubes outdoor	2,0	36,0		36,0	72,0	0,0	12,0	12,0	7,0	6048,0	864,0
3,0	Operation light	1,0	300,0		300,0	300,0	0,5	0,0	0,5	7,0	1050,0	150,0
4,0	Operation bed	1,0	240,0		240,0	240,0	0,5	0,0	0,5	7,0	840,0	120,0
5,0	Suction machine	1,0	90,0	119,0	111,0	111,0	0,3	0,0	0,3	1,0	27,8	4,0
6,0	Electro Surgery machine	1,0	600,0	35,0	20,0	20,0	0,5	0,0	0,5	7,0	70,0	10,0
7,0	Anestesia machine	1,0	320,0	103,0	91,0	91,0	0,5	0,0	0,5	7,0	318,5	45,5
8,0	Air conditionning	1,0	1348,0		1348,0	1348,0	0,5	0,0	0,5	7,0	4718,0	674,0
Total					2182,0	2398,0	8,8	14,0	22,8		25168,3	**3595,5**
Maternity ward												
1,0	Light tubes indoor	7,0	36,0		36,0	252,0	0,0	12,0	12,0	7,0	21168,0	3024,0
2,0	Light tubes outdoor	1,0	36,0		36,0	36,0	0,0	12,0	12,0	7,0	3024,0	432,0
3,0	Energy saver bulbs	8,0	18,0		18,0	144,0	0,0	12,0	12,0	7,0	12096,0	1728,0
4,0	Laundry Machine	1,0		643,0	327,0	327,0	4,5	0,0	4,5	5,0	7357,5	1051,1
5,0	Suction machine (1)	1,0	90,0	132,0	120,0	120,0	0,3	0,0	0,3	0,1	2,1	0,3
6,0	Suction machine (2)	1,0	90,0	120,0	114,0	114,0	0,0	0,0	0,0	7,0	0,0	0,0
7,0	Baby warm air machine (1)	1,0	800,0	567,0	560,0	560,0	0,5	0,0	0,5	7,0	1960,0	280,0
8,0	Baby warm air machine (2)	1,0	800,0	615,0	580,0	580,0	1,5	0,0	1,5	7,0	6090,0	870,0
9,0	Oxygen machine	1,0		454,0	417,0	417,0	0,3	0,0	0,3	7,0	729,8	104,3
10,0	Fridge	1,0		75,0	69,0	69,0	12,0	12,0	24,0	7,0	11592,0	1656,0
11,0	Electric teakettle	1,0	2000,0	1990,0	1974,0	1974,0	0,3	0,0	0,3	7,0	3454,5	493,5
Total					4251,0	4593,0	19,3	48,0	67,3		67473,9	**9639,1**

#	Items	Qty	Power (W)				Energy					
			Name plate	Measured value			Hours/Day	Hours/Night	Total Hours	Days/Week	Total Wh/week	Total Wh/Day
			Nominal rating	Maximum	Mean Operation	Total Mean Operation						
Shops												
1,0	Light tubes outdoor	15,0	36,0		36,0	540,0	0,0	12,0	12,0	6,0	38880,0	5554,3
2,0	Light tubes indoor	16,0	36,0		36,0	576,0	0,0	4,0	4,0	6,0	13824,0	1974,9
3,0	Fridge (1)(Mma Mguli)	1,0		344,0	276,0	276,0	6,0	2,0	8,0	6,0	13248,0	1892,6
4,0	Fridge (2) (Mma Mguli)	1,0	440,0	400,0	368,0	368,0	6,0	2,0	8,0	6,0	17664,0	2523,4
5,0	Fridge (3) (Chalo)	1,0	160,0	1179,0	156,0	156,0	6,0	2,0	8,0	6,0	7488,0	1069,7
6,0	Fridge (4) (Bundu)	1,0	200,0	1183,0	254,0	254,0	6,0	2,0	8,0	6,0	12192,0	1741,7
7,0	Fridge (5) (Mma Mwandu)	1,0		196,0	136,0	136,0	6,0	2,0	8,0	6,0	6528,0	932,6
8,0	Fridge (6) (Elibea)	1,0	429,0	497,0	403,0	403,0	6,0	2,0	8,0	6,0	19344,0	2763,4
9,0	Fridge (7) (Elibea)	1,0		1345,0	259,0	259,0	6,0	2,0	8,0	6,0	12432,0	1776,0
10,0	Fridge (8) (Jijeng)	1,0	366,0	352,0	300,0	300,0	6,0	2,0	8,0	6,0	14400,0	2057,1
11,0	Fridge (9) Ebenzer	1,0	220,0	1074,0	177,0	177,0	6,0	2,0	8,0	6,0	8496,0	1213,7
12,0	Fridge (10) Ebnezer	1,0	450,0	490,0	420,0	420,0	6,0	2,0	8,0	6,0	20160,0	2880,0
13,0	Fridge (11) Nemma	1,0		111,0	110,0	110,0	6,0	2,0	8,0	6,0	5280,0	754,3
14,0	Fridge (12) Tuge	1,0	180,0	397,0	380,0	380,0	6,0	2,0	8,0	6,0	18240,0	2605,7
15,0	Fridge (13) Mma Horro	1,0		363,0	315,0	315,0	6,0	2,0	8,0	6,0	15120,0	2160,0
16,0	Fridge (13) Mma Horro	1,0		360,0	216,0	216,0	6,0	2,0	8,0	6,0	10368,0	1481,1
17,0	Photocopy machine (Ebenzer)	1,0		531,0	371,0	371,0	0,2	0,0	0,2	6,0	445,2	63,6
18,0	Photocopy machine (Elibea)	1,0		818,0	357,0	357,0	0,3	0,0	0,3	6,0	535,5	76,5
19,0	Photocopy machine (Esta))	1,0		1345,0	337,0	337,0	0,2	0,0	0,2	6,0	404,4	57,8
20,0	Computer (Esta)	1,0		125,0	114,0	114,0	2,0	0,0	2,0	6,0	1368,0	195,4
Total					5021,0	6065,0	86,7	44,0	130,7		236417,1	**33773,9**

#	Items	Qty	Power (W)				Energy					
			Name plate	Measured value			Hours/Day	Hours/Night	Total Hours	Days/Week	Total Wh/week	Total Wh/Day
			Nominal rating	Maximum	Mean Operation	Total Mean Operation						
Private ward												
1,0	Light tubes indoor	15,0	36,0		36,0	540,0	0,0	12,0	12,0	7,0	45360,0	6480,0
2,0	Light tubes indoor	1,0	36,0		36,0	36,0	12,0	12,0	24,0	7,0	6048,0	864,0
3,0	Light tubes outdoor	2,0	36,0		36,0	72,0	0,0	12,0	12,0	7,0	6048,0	864,0
4,0	Energy saver bulbs	1,0	18,0		18,0	18,0	0,0	12,0	12,0	7,0	1512,0	216,0
Total					126,0	666,0	12,0	48,0	60,0		58968,0	**8424,0**
Overall total Energy [Wh/day]					**704927,7**							
Overall total Instantaneous Power [W]					**135465,0**							