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Assessment Of Renewable Energy Technologies For Remote Area Wireless Base Transceiver Station To Reduce Carbon Footprint: A Case Study In Dolpa (nepal)

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Neha Karn

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled "Assessment of renewable energy technologies for remote area wireless Base Transceiver Station to reduce carbon footprint: A case study in Dolpa (Nepal)" submitted by Ms. Neha Karn in partial fulfillment of the requirements for the degree of Master in Climate Change and Development.

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ABSTRACT

Dolpa, the largest district of Nepal covering 5.36% of the total landmass of the country, has huge expenditure on energy result due to the lack of grid availability and transportation difficulties which highlights a potential barrier to telecom industry growth. Uncertainty in power availability has compelled telecom operators to use diesel generators system (DGs) to ensure a continuous supply of power for network availability. DG consumed 22,174 liters in a year, average fuel per day 60.8 liters of diesel and average fuel per hour consumption was 2.53 liters of diesel. CO_2 emission was found to be 58,048 kg followed by 362 kg of CO emission per year per telecom tower. Net Present Cost was $502,363.30 and Levelized cost of energy($/kWh) was $4.75. Though the amount has been reduced due to the availability of on grid power but still there are many off grid place which uses diesel powered system. So, it becomes an imperative solution for telecom operators to evaluate all alternative energy sources to power such telecom towers in order to increase network reliability with reduced energy cost. Renewable energy systems (solar, wind, solar-wind hybrid,) with DG and storage system can be applied successfully in those areas where grid connection is not available or considered uneconomical.

This study identifies possible renewable energy technologies (RETs) to evaluate a better solution. This study report also presents the techno-economic analysis of various RET based models for powering remote telecom towers. While a comparative study has been done between RET powered system, DG Powered system and various Hybrid models in terms of their cost of energy production and greenhouse gas (GHG) emissions. As a case study of tower the site location chosen here, models has been optimized using HOMER (Hybrid Optimization Model for Electric Renewable) and best suited model is suggested for the case that is identified.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

ISSN: 2278-0181

LIST OF ABBREVIATIONS

ADB	Asian Development Bank
ASDC	Atmospheric Science Data Center
ATS	Automated Telecommunication Station
BSC	Base Station Controller
BSs	Base Stations
BSS	Base Station Subsystem
BTS	Base Transceiver Station
CAPEX	Capital Expenditure
CO	Carbon Mono-oxide
CO_2	Carbon Di-oxide
CSP	Concentrated Solar Power
DHM	Department of Hydrology and Metrology
DG	Diesel Generator System
E^3F	Energy Efficiency Evaluation Framework
EARTH	Energy Aware Radio and Network Technologies
ESP	Earth System Physics
GB	Generator Battery System
GCM	General Circulation Model
GDP	Gross Domestic Product
GHG	Green House Gas
GPMS	Green Power Management Solutions
GS	Generator System
GSM	Global System for Mobile Communication
GSMA	Group Special of Mobile Association
HFCs	Hydrofluorocarbons
HOMER	Hybrid Optimization Model for Electric Renewables
ICBC	Initial Condition Boundary Condition
ICT	Information and Communication Technology
ICTP	International Centre for Theoretical Physics
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LTE	Long Term Evolution

NCAR	National Centre for Atmospheric Research
NEEP	National Energy and Evaluation Program
NT	Nepal Telecom
OPEX	Operating Expenditure
PFCs	Perfluorocarbons
PV	Photovoltaic
PPV	Photovoltaic Power
Reg CM	Regional Climate Model
RCP	Representative Concentration Pathways
RETs	Renewable Energy Technologies
RMS	Root Mean Square
SATRC	South Asian Telecommunication Regulator's Council
SB	Solar Battery System
SF_6	Sulfur Hexafluoride
SGB	Solar Generator Battery System
SWB	Solar Wind Battery System
SWBG	Solar Wind Battery Generator System
SRES	Special Report on Emission Scenarios
SST	Sea Surface Temperature
SWERA	Solar and Wind Energy Resource Assessment
UE	User Equipment
UMTS	Universal Mobile Telecommunication System
UNFCCC	United Nations Framework Convention on Climate Change
VSAT	Very Small Aperature Terminal Antenna
WB	Wind Battery System
WEP	Wind Energy Potential
WGB	Wind Generator Battery System

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CHAPTER ONE: INTRODUCTION

1.1 Study background

Climate change is one of the most compelling global challenges of our time. There has been a considerable increase in the average temperature of the earth in the past century. This rise in temperature is attributed to the effects of global warming brought about by the accumulation of GHG in the atmosphere. The reason for increased GHG, mainly CO_2, is because of the increased energy consumption which results in emission of pollutants. Natural calamities like typhoons, floods and changes in the sea levels are attributed to the CO_2 fueled greenhouse effect. It is estimated that during the last 30 years the CO_2 emissions have gone up by 73%. The information and communications technology (ICT) industry alone accounts for about 2% or 860 million tons of the world's greenhouse gas emissions. The main contributing sectors within the ICT industry include the energy requirements of PCs and monitors (40%), data centers about 23% and fixed and mobile telecommunications contribute about 24% of the total emissions. Compared to the other sectors such as travel and transport, construction and energy production, the ICT sector is relatively energy-lean with telecommunications contributing just 0.7 percent or about 230 million tons of greenhouse gas emissions (SATRC,2012). The challenge for the telecom service providers, telecom equipment manufacturers and the government is to pursue growth in telecom networks, while ensuring that the 2 percent of global emissions does not significantly increase over the coming years.

Increasing public demand for corporate social responsibility and a genuine desire to effect positive change in the environment are leading telecommunications service providers and their suppliers to reduce their carbon footprint. Going Green has also become a business necessity for telecom operators with energy costs becoming as large as 25% of total network operations cost. A typical communications company spends nearly 1% of its revenues on energy which for large operators may amount to hundreds of crores of rupees. (SATRC,2012)

Whether out of compulsion of reducing cost or fulfilling corporate social responsibility (CSR) and projecting a humane face to the society, telecom service providers and manufacturers, all over the world, have taken steps towards greening of telecom. Efficient power management, infrastructure sharing, use of eco-friendly renewable energy sources and cutting down carbon emission over the complete duration of the product lifecycle have been under intense consideration by telecom industry all over the world.

1.2 Carbon Footprint of Telecommunications Industry

GHG are gases in the atmosphere that absorb and emit radiation within the thermal infrared range. These gases prevent heat from escaping from the atmosphere and make the earth warmer. This process is the fundamental cause of the greenhouse effect. The main greenhouse gases in the earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, ozone and chlorofluorocarbons. Human activities add significantly to the level of naturally occurring GHG. Some gases such as HFCs, PFCs, and SF_6 result exclusively from human industrial processes. Greenhouse gases vary in their ability to absorb and hold heat in the atmosphere. HFCs and PFCs are the most heat-absorbent. Nitrous oxide absorbs 270 times more heat per molecule than carbon dioxide, and methane absorbs 21 times more heat per molecule than carbon dioxide.

Carbon footprint is the total set of GHG emissions caused by an organization, event or product through burning fossil fuels for electricity. For simplicity of reporting, it is often expressed in terms of the amount of CO_2 or its equivalent of other GHGs, emitted. It is expressed in equivalent tonnes of CO_2. A carbon footprint is a measure of the impact our activities have on the environment, and in particular climate change. Carbon footprints can be classified into primary and secondary footprints:

- The primary footprint is a measure of the direct emissions of CO_2 from the burning of fossil fuels for the activities of the entity being carbon foot printed. For a telecom service provider it would include, for example, network operation cost, building lighting and cooling or heating and transportation. The service provider would have direct control over these.

- The secondary footprint is a measure of the indirect CO_2 emissions associated with the manufacture and eventual breakdown during the whole lifecycle of the products that are used. Energy consumed in the manufacture of equipment like BTS causes secondary footprint for the service provider who uses it.

1.3 Carbon Emission from Telecom sector

Mobile subscriber base crossed 5 billion mark in July 2010 and expected to cross 8 billion by 2020. With increasing demand for telecom services, the energy consumption has also grown significantly and poses an environment challenge in terms of larger carbon emission footprint of the telecommunication industry. The total global carbon footprint of the ICT industry as a whole is in the order of 860 million tonnes CO_2 which is approximately two percent 2% of the global emissions. Of this, the contribution from global telecommunication systems-mobile, fixed and communication devices are around 230 million tons CO_2 or approximately 0.7% of global emissions. (SATRC,2012)

To understand the contributory factors to the telecom carbon foot print one need to assess the emission of telecom network, particularly the wireless telecom network. For any telecom operator the network uses 86% of the energy. The tower sites use 65% and the core network 21%. As compared to this all vehicles use just 1% and the corporate office 12% .(SATRC,2012)

Reduction of the GHG produced or caused to be produced by the telecom sector is referred to as greening of telecom. Green telecom has many facets. It can be classified broadly in terms of greening of telecom networks, green telecom equipment manufacture, environment friendly design of telecom buildings and safe telecom waste disposal. These aspects are briefly described below:

- **Green Telecom Networks**: In telecom networks greening would refer to minimizing consumption of energy through use of energy efficient technology, using renewable energy sources and eco-friendly consumables.

- **Green Manufacturing:** The greening process would involve using eco-friendly components, energy efficient manufacturing equipment, electronic and mechanical waste recycling and disposal, reduction in use of hazardous substances like chromium, lead and mercury and reduction of harmful radio emission.

- **Design of green central office buildings:** Optimization of energy power consumption and thermal emission, minimization of green house gas emission

- **Waste disposal:** Disposal of mobile phones, network equipment etc., in an environment-friendly manner so that any toxic material used during production does not get channelized into the atmosphere or underground water.

1.4 Motivations for Green Telecom

A number of factors have led to heightened interest in greening of service sector industries. In the case of telecommunications, the factors that are leading to enhanced action on greening are as follows:

(i) Need to reduce the cost of operations of the telecom network by reducing energy cost.

(ii) Need to expand network into rural areas where power availability is poor.

(iii) Renewable energy technology becoming available at increasingly reducing cost.

(iv) Confluence of socio-political trends towards environmental responsibility, pressure groups against global warming.

(v) Creating sustainable businesses has become important where the objective is not only to create products and services through ethical means but also minimize environmental impact and improve communities.

1.5 Carbon Credit Policy for Telecom Industry

One carbon credit is equal to one tonne of carbon dioxide, or in some markets, carbon dioxide equivalent gases. A carbon credit is a generic term meaning that a value has been assigned to a reduction or offset of greenhouse gas emissions. A country needs to have a carbon credit policy to encourage reduction of carbon footprint. Such a policy is administered by the Government or a nominated authority. The policy would usually involve setting a limit or cap on the amount of a GHG that can be emitted by a company or an industry. The limit or cap is allocated or sold to firms in the form of carbon credits which represent the right to emit or discharge a specific volume of the greenhouse gasses. Firms are required to hold a number of carbon credits equivalent to their emissions. The total number of credits cannot exceed the cap, limiting total emissions to that level. Firms that need to increase their credits must buy them from those who have a smaller footprint than permitted. This transfer of credits is referred to as carbon trading. Such policies could include economic instruments, government funding and regulation.

1.6 Global Initiatives on Green Telecommunications

China Mobile has one of the world's largest deployments of green technologies to power its base stations. China Mobile had 2,135 base station powered by alternative energy in 2008. Of these 1,615 were powered by alternative solar energy, 515 by solar and wind energy and 5 by other alternative sources. According to a study low-carbon telecommunications solution saved China 48.5 million metric tons of direct carbon dioxide emissions in 2008 and 58.2 million metric tons in 2009 and projected to deliver as much as 615 tons in carbon savings by the year 2020.

Active sharing agreements have been entered into by T-mobile and 3 Group in UK, Telstra and3 Group, as well as Vodafone and Optus, in Australia, Tele 2 and Telia in Sweden. Swisscom has successfully implemented its "Mistral Mobile" cooling system at 30 of its BTS, leading to a reduction of up to 80% in the energy needed for cooling mobile network equipment.

Globally, BT gets credit for being one of the most aggressive in reducing its carbon footprint. The company's 2006 CO_2 footprint measurement in the United Kingdom was .64 million metric tons of carbon emissions — a reduction of 60% from its 1996 total of 1.6 million metric tons. BT has pledged an 80% reduction of its 1996 total by 2016. In the U.K., nearly all of BT's electricity now comes from renewable sources and combined heat and power plants. (SATRC 2012)

1.7 Lessons Learnt from Global Initiatives

Green Telecommunication challenges the norms of the design and construction industry. Design teams must actively search for better alternatives to conventional models to successfully reduce the environmental impact related to Telecommunication construction and uses. This search requires an improved decision model that balances cost, function and the environment. The result is an approach that expands the traditional "cost-benefit" decision model to one that includes environmental performance as a core value. Early on, the design team focused on explicitly defining environmental objectives, then tracking progress at each stage of design. To support this effort, an open, collaborative process was established which enhanced dialogue and decision making. Design innovations led not only to the creation of a more environmentally sound facility, but to improved quality and lower operating costs as well. Even though this green design process required extensive research and investigation of design alternatives, the group found that the overall design process gained efficiencies from the use of an inclusive approach. Guided by clear goals and defined milestones, this approach gave a sharp focus to the design effort.

1.8 Measures for Reducing Telecom Carbon Footprint

1. Adoption of energy efficient equipment and innovative technologies:

Energy costs account for more than half of mobile operators' operating expenses and about 65% of this is for the tower site equipment. Therefore, radio network solutions that improve energy-efficiency are not only good for the environment; they also make commercial sense for operators and support sustainable, profitable business. In general larger equipment have greater energy requirement. Today, such energy – in the region of 10 kilowatt – is being provided by diesel generators, which leave a large carbon footprint. It may be possible to design distributed systems that are spatially separated and together serve a large area and yet requires lesser energy than, say 1 kilowatt at each location. (SATRC,2012)

2. Use of Renewable sources of energy:

Renewable energy is energy generated from natural resources such as water, sunlight, wind, rain, tides, fuel cells and biomass sources as energy crops. Renewable energy sources are energy sources that are continually and naturally replenished in a short period of time. In contrast, fuels such as coal, oil, and natural gas are non-renewable. RETs are those that utilize energy sources in ways that do not deplete the Earth's natural resources and are as environmentally benign as possible. These sources are sustainable in that they can be managed to ensure that they can be used indefinitely without degrading the environment. By exploiting these energy sources, RETs have great potential to meet the energy needs of rural societies in a sustainable way, albeit most likely in tandem with conventional systems. The decentralized nature of some RETs allows them to be matched with the specific needs of different rural areas.

Where sites are beyond the reach of an electricity grid or where the electricity supply is unreliable, and are remote enough to make the regular maintenance and refueling of diesel generators prohibitive, there are several cost-effective alternative energy sources available. The importance of these alternative energy sources is increasing as the costs of expanding into remote areas grow. As radio sites have become more energy-efficient, it has become more economically and technically feasible to use alternative energy sources. The following approaches have been considered singly or in combination:

- Solar energy
- Wind energy
- Ocean/Tidal energy
- Pico hydro energy
- Biomass energy
- Fuel cell energy

3. Better network Planning:

Network planners can help reduce the carbon footprint in a number of ways. New network design methodologies, radio techniques and site technologies have been developed to reduce energy consumption across the board: from radio equipment, through climate and power systems to radio access networks with a focus on improving both new network roll-out, as well as the operation of existing networks. Energy consumption can be reduced if network solutions and services can be designed to use fewer sites and to reduce energy consumption.

Nepal:

Code of Practice encompassing energy efficient Network Planning, active infra-sharing, deployment of energy efficient technologies and adoption of RET including the following elements: (SATRC,2012)

i. The network operators should progressively induct carefully designed and optimized energy efficient radio networks that reduce overall power and energy consumption.
ii. Service providers should endeavor to ensure that the total power consumption of each BTS will not exceed 500W by the year 2020.
iii. Sharing of the infrastructure using passive as well active methodologies should be done to minimize the eventuality of locating new sites within the vicinity of existing towers. [Say within 200m, in urban areas & within 2 Km, in rural areas].
iv. A phased programmed should be put in place by the telecom service providers to have their cell sites, particularly in the rural areas, powered by hybrid renewable sources including wind energy, solar energy, fuel cells or a combination thereof.

v. Service providers through their associations should consensually evolve the voluntary code of practice and submit the same to Regulator before the end of fiscal year.

1.9 Way Forward

The policy makers, regulators and service providers should consider the followings for future:

- Adoption of energy efficient equipment and innovative technologies
- Use of Renewable sources of energy
- Infrastructure Sharing
- Improvement of grid supply
- Waste Management
- Better network planning: more outdoor BTS, less BTS, less air-conditioning requirement to cool sites
- Standardization of equipment, test and certification
- Monitoring and reporting
- Government support – subsidies, taxes & levies

Every year, 120,000 new base stations are deployed servicing 400 million new mobile subscribers around the world (Amanna, 2010). Remote regions often rely on inefficient diesel generators for power, which will significantly grow the carbon footprint of telecommunications. So, to curb the power issues and the need to reduce carbon emissions, it has become imperative for the telecom industries to evaluate all alternative options in order to provide better network availability and to reduce energy costs. The growing cost of energy due to diesel prices and concerns over rising greenhouse emissions have caused tower infrastructure companies to focus on better power management methods. Various methods in the categories of demand management, supply management and RETs are being adopted. The current trial deployment of RET solutions like solar photovoltaic, wind power, biomass and fuel cells across the world are proving that each RET has its own challenges but no single RET provides a silver bullet solution while the majority of these trials have been with solar photovoltaic technology.

Nepal has about 6500 telecom towers (NTA, 2017) and poised to increase to 7,000 shortly. Telecom towers technically known as BTS or sometimes BSC are the most energy intensive part of the cellular network. It is noted that the GSM energy consumption are considerably higher than the UMTS technology, as it is expected because of the different mode of operation of the two technologies (Lubritto, 2011). They require continuous power supply from 500 W to 5000W depending upon the system capacity (older installation consumes more power than new one because of technological advancement). This would mean the consumption of energy between 12 to 120 KWh per day in different cases. Since, traffic load in mobile communication networks significantly varies during a working or weekend day, the base station power consumption varies accordingly. Whereas, electricity supply is erratic and is not available throughout the day in many parts, diesel generators have been the choice of telecom operators in spite of their higher OPEX and carbon imprint.

The telecom operators annually spends $66,679 per telecom towers towards running diesel generators in remote locations where grid base power is limited which translates to an operational energy expense of around 80 to 90% of total operating costs (Intelligent Energy, 2012). DGs are operational for 10-12 hours in average in rural areas putting a stress on the environment through carbon emission and noise pollution.

1.10 Need

The growth of number of subscribers requires more towers to ensure network availability. But the lack of adequate electrical grid infrastructure in Nepal is restricting the infrastructural development like telecom, real-estate and transport among others.

What prompted the need for this thesis is the observation made that the most of the remote telecom towers running on diesel generators resulting a very high amount of CO_2 emissions in the atmosphere. This necessitates for telecom infrastructure companies turning into 'Green Power Management Solution' for the better network availability with continuous supply of power and for the sustainable growth of the industries themselves. In that case, renewable energy technology solution could be the best option. Clean Energy Technology is essential for limiting global warming and protecting ecosystems by reducing CO_2 emissions.

1.11 Rationale

Due to the unreliable electrical power grid, tower infrastructure companies use diesel generators, batteries and a variety of power management equipment to back up the grid and ensure network availability. Operational costs in remote reasons are aggravated more due to transportation difficulties and obviously due to the rise in diesel price. In Nepal diesel price has increased from NPR 55/liter in 2065 to NPR 95/liter in 2075 (NOC, 2019). It is expected that deregulation of diesel prices, if continued with current regulatory fees, tax structure and marketing margin, would result in an increase in diesel price further in upcoming days. In other words, energy costs could constitute more than 90% of the cost of operating telecom towers, everything else being constant. So, to curb the power issues, sustainable growth and development, an integration of energy efficient and clean power consideration for telecom operations is necessary to provide best possible quality of service in telecom sector.

The reduction of the energy consumptions of a Telecommunication Power System represents one of the critical factors of the telecommunication technologies, both to allow a sizeable saving of economic resources and to realize “sustainable” development actions. The consumption of about one hundred base stations for mobile phones were monitored for a total of over one thousand days, in order to study the energy consumption in relation to the environmental, electric and logistics parameters of the stations themselves. It was possible to survey, then, the role of the mobile communication systems in the general national energy framework and to plot the best areas of intervention for saving energy and improving the environmental impact, showing the role played by air-conditioning and transmission equipment’s. Finally, new transmission algorithms and the use of renewable energy based techniques have been tested.

Nepal uses little energy, inefficiently, but consumption is growing from 2000 to 2013, Nepal’s energy consumption grew 27%, from 8.04 to 10.17 million tonnes of oil equivalent (mtoe) (IEA, 2016). Between 1990 and 2010, industry’s energy demand grew 9% annually, while transport’s demand grew 6.4% per year (ADB, 2015). Despite this growth, Nepal’s energy demand remains among the lowest in Asia (ADB, 2015). While the overall quantity of energy that Nepal consumes is low, the amount of energy consumed relative to economic output is very high. In fact, Nepal’s energy intensity the amount of energy consumed per unit of GDP is 1.8 times higher than India and China, 4.5 times higher than Bangladesh, and 4.5 times the world average. (NEEP, 2015) Nepal’s high energy intensity suggests that it has significant potential to increase both its use of energy for productive purposes and the energy efficiency of its production .(ADB, 2015)

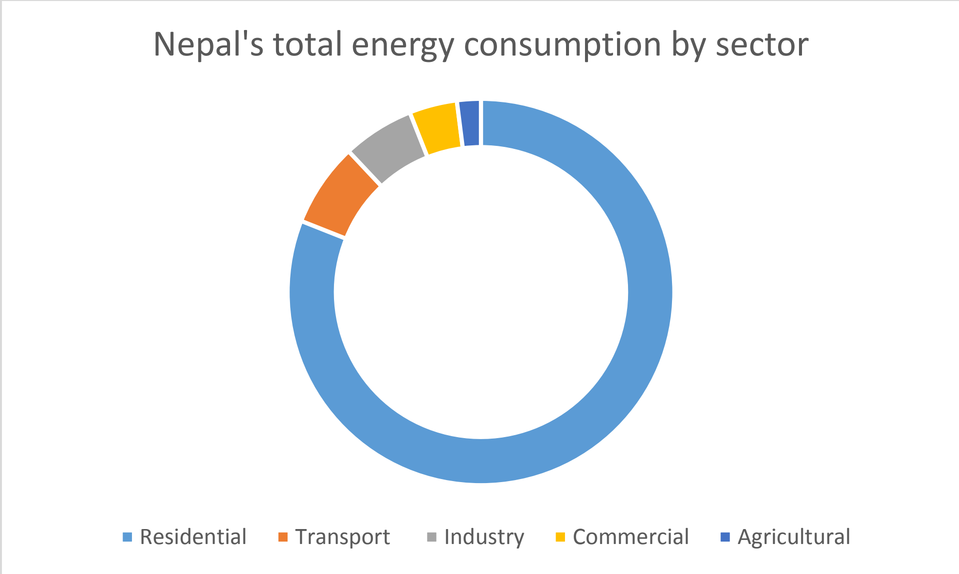

Figure 1 : Nepal's total energy consumption by sector

In 2013, transport, industry, and commercial and public services accounted for only 7%, 6% and 2% of Nepal's energy consumption, respectively. (source EEG, 2016)

1.12 Telecommunications power systems and environmental monitoring

It becomes very important to study the relation between energetic aspect, environmental impacts and radio-telecommunication power systems. One can consider at least three different relevant contexts:

•Impact of BTS on the landscape

• Electromagnetic pollution generated by the BTS

• Environmental impact coming from further polluting agents (emission of /greenhouse gases, noise, etc.)

The telecommunication sector plays a significant role in shaping the global economy and the way people share information and knowledge. At present, the telecommunication sector is liable for its energy consumption and the amount of emissions it emits in the environment. In the context of off-grid telecommunication applications, off grid base stations (BSs) are commonly used due to their ability to provide radio coverage over a wide geographic area. However, in the past, the off-grid BSs usually relied on emission-intensive power supply solutions such as diesel generators. In this review paper, various types of solutions (including, in particular, the sustainable solutions) for powering BSs are discussed. The key aspects in designing an ideal power supply solution are reviewed, and these mainly include the pre-feasibility study and the thermal management of BSs, which comprise heating and cooling of the BS shelter/cabinets and BS electronic equipment and power supply components. The sizing and optimization approaches used to design the BSs'power supply systems as well as the operational and control strategies adopted to manage the power supply systems are also reviewed in this paper. Diesel generators used to be widely deployed for powering BSs; however, over time, the idea of using diesel generators as a primary or back-up power supply has become less favorable due to the challenges linked to their reliability, availability, high operational and maintenance (O&M) costs, and their significant environmental impacts. In the context of powering off-grid BSs, key features such as the economic, environmental, and social sustainability of BSs are critically important. Hence, methods using renewables coupled with sustainable energy storage solutions are now receiving more attention than before.

1.13 Importance

Based on the short term field work and case study, applying a theoretical and substantive engineering knowledge, this thesis work tried to explore the ways and means by which the telecom growth story could be made sustainable with renewable energy technologies. It has attempted to describe the greening of telecom towers using energy efficient technologies and eco-friendly sources. This study reveals the following importance.

1. Reduction of cost of operations of the telecom network by reducing energy cost.
2. Expanding network into rural areas where power availability is poor.
3. Availability of renewable energy technology at low costs.
4. Confluence of socio-political trends towards environmental responsibility and pressure group against global warming.
5. Creating sustainable businesses where the objective is not only to create products and services through ethical means but also to minimize environmental impact and help local communities.

Throughout this thesis work, I, Neha Karn as a researcher, evaluated the possible RET solutions suitable for powering remote telecom towers of Nepal. Meanwhile, technological characteristics, their economics, suitability and limitations of such RETs are discussed. More intensely, this thesis work is concentrated on solar, wind and/or solar-wind hybrid system technology in powering remote telecom towers in contrast with diesel generator

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system alone with their solution configuration, economic analysis and environment analysis.

1.14 Objectives

1.14.1 General objectives

To explore the increasing carbon footprint of telecom towers in Nepal and identify the best suited technology by evaluating technical, economic and environmental impact of all the possible RETs solutions to power remote telecom towers.

1.14.2 Specific Objectives

a. To investigate existing system model and potential energy solution for remote telecom towers of selected site Dolpa (Nepal).
b. To assess possible technologies and analyze techno-economic and environmental evaluation for those technologies in powering remote telecom towers using HOMER.
c. To identify the best optimized technology for selected site by assessing its facilities, potential saving and reduction of CO_2 emission.

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CHAPTER TWO: LITERATURE REVIEW

2.1 Motivating factors for hybrid powered BS's

In addition to the environmental benefits of using renewable energy sources, solar powered BSs have a number of additional advantages. This section presents the various advantages and other factors that have motivated the increasing deployment of solar powered base stations.

1. Cost Saving :

Although solar powered BSs have a high CAPEX, the OPEX is much smaller, leading to cost savings on the long run. Solar powered BSs do not require the laying of cables for grid connections, which reduces the CAPEX and also speeds up the deployment. Also, the cost of solar panels has decreased significantly over the years, with their efficiency increasing every year. The bulk of the savings in the OPEX comes from the cost of energy, specially in areas without grid connectivity where network operators have to rely on diesel generators. The OPEX for solar powered BSs primarily comprises of the cost of replacing the batteries (required every 2-8 years based on the battery usage pattern). (Chamola,2016)

2. Generator Operation:

The use of a renewable energy source implies that there are no harmful emissions during the operational stage. Consequently, the deployment of renewable energy powered BSs is encouraged by many governments and telecom operators.

3. Simpler Maintenance:

BSs powered by diesel generators have greater maintenance requirements as well as the need to regularly refill the fuel for the generators. In comparison, renewable energy powered BSs have lower maintenance needs and such sites can easily be unmanned.

4. Greater disaster resistance:

Traditional grid connected BSs fails in the case of extended grid failure. For example, during the 2011 earthquake in Japan followed by a tsunami, more than 6,700 cellular BSs experienced outages. In contrast, renewable energy powered BSs are immune to grid outages and can restore their services faster.

5. **Government regulations and subsidies:**

Many countries currently offer subsidies for promoting the use of renewable energy that can lower the CAPEX of installing renewable energy powered BSs. In addition, some governments are making it mandatory for telecom operators to have a certain fraction of their BSs powered by renewable energy (e.g. in India).

6. **New base stations with low power consumption:**

Recent developments in the design of cellular network infrastructure have resulted in macro base stations that consume around 500-800 W and smaller base stations that consume around 50-120 W, making renewable energy powered BSs a practical alternative to traditional BSs. (Chamola,2016)

2.2 Key components of Hybrid BSs

2.2.1 Base station subsystem (BSS)

2.2.1.1 Traditional base station:

A traditional base station consumes 0.5-2 kW based on the type. The power consumption of a traditional base station is shared by the radio equipment(power amplifier) which consumes around 65% of the overall power, followed by the cooling equipment and base band processing which consumes around 17% and 10%, respectively. Rest of the power is used for the control operations. The cooling is for both the batteries as well as the radio equipment (which is generally done by air conditioners and in some rare cases using an ordinary fan). (Chamola,2016)

2.2.1.2 Next generation base stations:

In contrast to the traditional base stations, as a result of telecom companies and BTS manufacturers looking for reducing power consumption of the base station, many newmodels for base stations have been developed which are becoming increasingly popular. For example, Nokia Siemens has introduced flexi BSs which require reduced installation cost and time, are much more compact and lighter, and achieve up to 70% reduction in site power (Chamola,2016).

Based on whether a BS is connected to the power grid, the BS is classified as an on-grid

BS or an off-grid BS. The power supplies for an on-grid BS can be grid power and green power from either the standalone green power generator or from the green power farm, e.g., a solar/wind farm. An off-grid BS may be powered by regular power (non-renewable energy such as diesel) and green power from either individual generator or green power farm.

On-grid Green Mobile Networks refer to as the mobile networks whose BSs are not only connected to power grid but also equipped with standalone green power generators.

2.3 Remote Telecommunication

The main motive of this research study is to power a remote telecom tower of Nepal with RET options. Here, the term "remote" specifically defined as "the area with no grid availability" as per the scope of this study report. The literal meaning of 'remote' is an area located far away spatially which may be hardly accessible or sparsely populated. On the other hand a remote telecom is a communication mechanism with a data processing facility from remote location or facility through a data link. In terms of services and infrastructure development remote area always lack behind all those opportunities. Global telecommunication is the one which has an intention to serve people via communication link at every nook and corner of the globe. In order to connect people, a better telecommunication infrastructure must be developed challenging all geographical difficulties. While infrastructure itself is insufficient without power, here the point comes, most of the remote location of Nepal do lack in reliable power. On the other hand, there are some other location that do have an access of power from grid or sometimes from micro hydro power stations (MHPS) but no transportation facility even there exist a high traffic demand.

To my purpose, I considered a remote location as an area that do not have grid availability, whether it has sophisticated transportation facility or not. As a matter of fact, due to the recent hydropower development agreements and ongoing hydropower project, the lack of electricity supply seem to be scaled up within the next few years but the grid access to contribute remote telecom proceed after then with subsequent year of implementation hence, the study has larger scope for upcoming years. So, this research report tried to explore the possibilities to power remote telecom towers with an abundant resources like solar and/or wind, while cost associated with the system establishment with geographical constraints has been dealt separately.

2.4 Green Communication Concept

Growing telecommunications infrastructure requires increasing amount of electricity to power it. Part of the electricity comes from the power grid and remaining through burning of fossil fuel like diesel. Both of these sources contribute to emission of greenhouse gases (GHGs) with the attendant negative environmental effects. According to (TRAI, 2011), "reduction of the GHG produced or caused to be produced by the telecom sector is referred to as greening of telecom". Green telecom has many facets. It can be classified broadly in terms of greening of telecom networks, green telecom equipment manufacture, environment friendly design of telecom buildings and safe telecom waste disposal.

Regarding the telecom sector, one such solution is adaptation of Green Telecom Networks. Greening would refer to minimizing consumption of energy through use of energy efficient technology, using renewable energy sources and ecofriendly consumables. "Maximizing utilization of alternative energy sources like solar and wind power, the telecom sector can minimize CO_2 emission and thus it can bring its value in saving the planet". (Krishna, 2012)

2.5 Power Consumption in Cellular Networks

A typical cellular network consists of three main elements (1) A core network that takes care of switching (2) base stations providing radio frequency interface (3) and the mobile terminals in order to make voice or data communications. The power consumption is distributed across the different functionalities of the network like switching, core transmission, data center etc. But the base stations are the most energy intensive part of the cellular network (Figure 2).

"There are currently more than 4 million base stations (BSs) serving mobile users, each consuming an average of 25 MWh per year. In a traditional cellular network, the BSs consume over 60% of total energy". (Singh, 2012) .

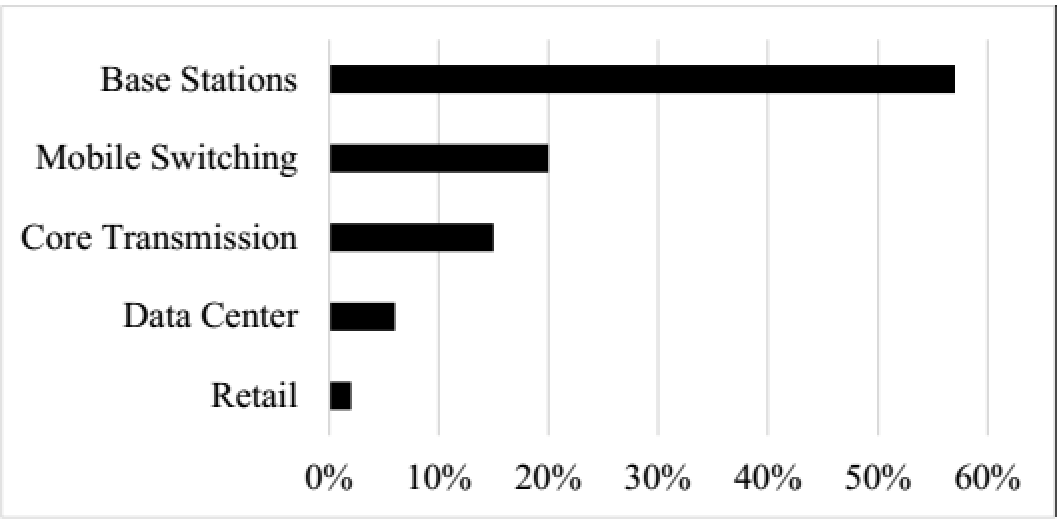


Figure 2 : Power Consumption of a Typical Wireless Cellular Network

Figure illustrates that the base stations has highest consumption of power, switching system has 20% of total, core transmission has 15%, data center has 6% and retail has 3% of consumption of power.

Energy Consumption/Technology

Technology	kWh/day	kWh/year
UMTS	72.97	26268
GSM	111.35	40085

Table 1 : Energy consumption for GSM and UMTS technology

Carrying out analyses on the average energy consumption associated to the different technologies, it is noted that the GSM energy consumption are considerably higher than the UMTS technology (Table 1) – as it is expected because of the different mode of operation of the two technologies (Lubritto, 2011).

Lorincz J. (2012) in his paper investigated the changes in the instantaneous power consumption of GSM and UMTS base stations (BS) according to their respective traffic load (Figure 2). The real data in terms of the power consumption and traffic load have been obtained from continuous measurements performed on a fully operated base station site. Measurement show the existence of a direct relationship between base station traffic load and power consumption. According to the relationship, a liner power consumption model for base station of both technologies were also developed.

According to the following figures, it is obvious that the power consumption of each BS is not constant according to time. Actually, the instantaneous power consumption of the BSs varies during a day and these variations are inherent for all the mobile technologies (GSM 900, GSM 1800 and UMTS).

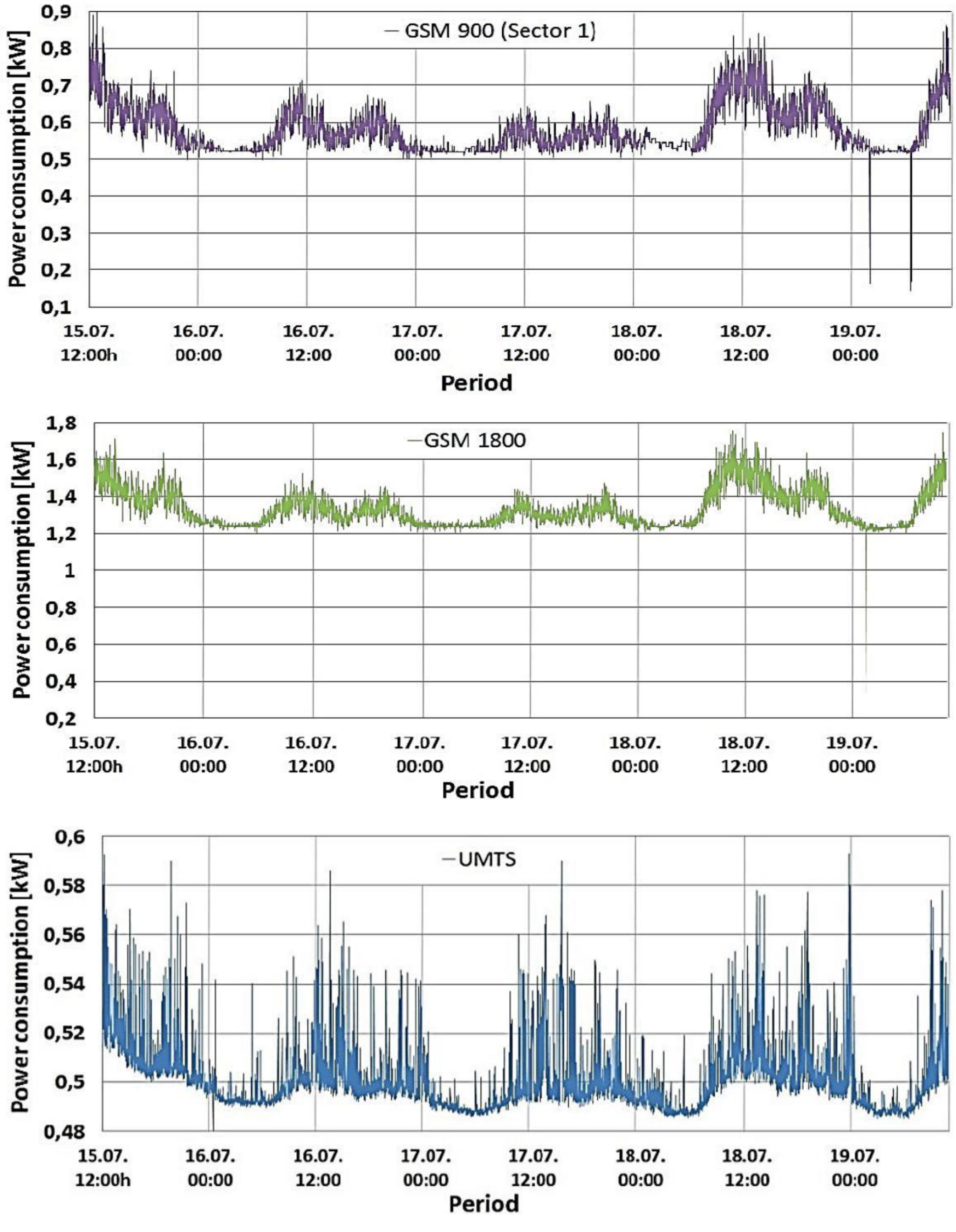


Figure 3: Power Consumption of GSM 900, GSM1800 and UMTS Base Stations Cabinet

From the study, it was found that the highest power consumer is the GSM 1800 BS. When compared with the BS of other technologies this BS has more than twice higher instantaneous power consumption at any moment. This is because GSM 1800 cabinetserves all of its sectors concurrently through configuration with its transceivers (TRXs) per sector. Since each TRX has a separate power amplifier which has the highest share in the BS power consumption, the number of TRXs have an important influence on the total BS power consumption. Therefore, compared with the number of TRXs in the GSM 900 and UMTS cabinets, higher number of TRXs in GSM 1800 BS cabinet is the main reason for having highest power consumption in the BS. In addition, the influence on the power consumption will be somewhat determined by the fact that the GSM 1800 BS has been selected for maximum capacity utilization.

Of all the on-site BSs, the UMTS BS has the lowest power consumption. This can be explained by the configuration having the minimum number TRXs and the newer technology characterized with BS hardware which is generally more energy efficient.

2.6 Green Power Management in Telecom Sector

Towards the solution of the problem, telecom infrastructure companies are now turning into GPMS with strategic implementation of renewable energy technologies like solar, wind, biomass, fuel cell, pico-hydro etc. Such strategic implementation of GPMS can be broadly classified into three categories:

2.6.1 Demand Management (Reducing Consumption)

Activities like passive infrastructure sharing, replacement of old BTS with new generation BTS, usage of outdoor BTS, optimized cooling at shelter, usage of intelligent transceivers (TRXs), reduction of air conditioner load by using cold ambient air for shelter cooling and operating air conditioners using stored energy in the batteries to reduce diesel consumption and carbon emission are some of the initiatives that have been implemented so far.

In the last four years with the evolution of technology, the typical power consumption of BTS has dropped by about 60%. "As per Bharti Infratel, introduction of Free Cooling Units (FCU) used in place of air conditioners will contribute to reduction of 4.1 million liters of diesel usage annually after deployment across 6,318 of its 34,220 tower sites". (India-Time News, 2012)

2.6.2 Supply Management (Increasing Efficiency of the Power Source)

Technologies like Integrated Power Management Systems (IPMS), Variable Speed DC Diesel Generators (DC-DG) and Fuel Catalysts are a few of the solutions that have been implemented to increase power source efficiency.

As per Bharti Infratel's P7 project, fuel consumption for similar load applications in case of DC-DGs is approximately 30% lesser than AC DGs. "By adopting DC-DGs at 2,000 sites, the consumption of diesel was reduced by 10.18 million liters annually". (Prasad, 2012)

2.6.3 Renewable Energy Adoption

Several cellular operators are experimenting with the use of alternative energy sources (Solar and Wind) for operating base stations. They can provide an energy efficient alternative to 'dirtier' and expensive fuel like diesel. In addition to the cost of the fuel itself, energy can be saved from minimizing the transport and storage of the fuel. In Namibia, the Mobile Telecommunications Limited (MTC) of Namibia, the GSMA Development Fund, and Motorola initiated a 90 day trial in 2007 to evaluate the use of solar and wind as a feasible cost-effective energy source for a cellular base station. This trial utilized a 6kW wind turbine and 28kW solar panels combined with battery capable of providing 60 hours of operations and monitoring equipment. The system provided an average of 198kW of power per week which was 10kWh more than necessary for acceptable operations. "MTC calculated a return on investment of 3 years that would save approximately 4,850 kg of CO_2 annually compared to a typical electrical grid installation. An addition 649.25kg CO_2 annually could be saved by eliminating the diesel generators". (Amanna, 2010)

Two rural Italian sites has been built with a photovoltaic (PV) plant in collaboration with Vodafone provider in order to obtain a total or partial architectural integration of the PV plants with infrastructure of the BTS. It has been shown that their energetic productivity depends on the geographical location, on the surface available to implement the PV plants and on the effects of shadow. In two of these pilot sites, "PV plants have been realized both on shelter and on the infrastructures; the area of PV modules varies from 16 to 20 m^2, limited by the available site space, to guarantee a yield of 2.0 and 2.5 kWP. These system came into operation on 01/01/2008 and monitored until 30/05/2008, producing respectively 1100 and 100 kWh; this implies an annual estimated production of 2640 and 2880 kWh. It is to be noted that such an application gives an environmental advantage of approximately 3 ton of not emitted CO_{2eq} per year for each BTS, besides the reduction of the pollution coming from further physical agents". (Lubritto, 2011).

2.7 Carbon Footprint of Mobile Communication

Assessing the ecological impact of mobile communication requires the study of a series of factors related to production, operation, and distribution of mobile communication networks and services. “A key factor of interest is the overall carbon footprint measured in CO_2 equivalent emissions (CO_{2eq}) calculated with the Global Warming Potential (GWP-100) indicator defined by the International Panel of Climate Change (IPCC)”. (Fehske A. , 2011).

In mobile communications, a large part of the carbon footprint stems from electricity consumption during operation and manufacturing, that is, from the production and distribution of electricity; from the extraction, production and distribution of fuels consumed; from the construction and operation of the power plants and the grid; and, finally, from all related waste treatment (Figure 4).

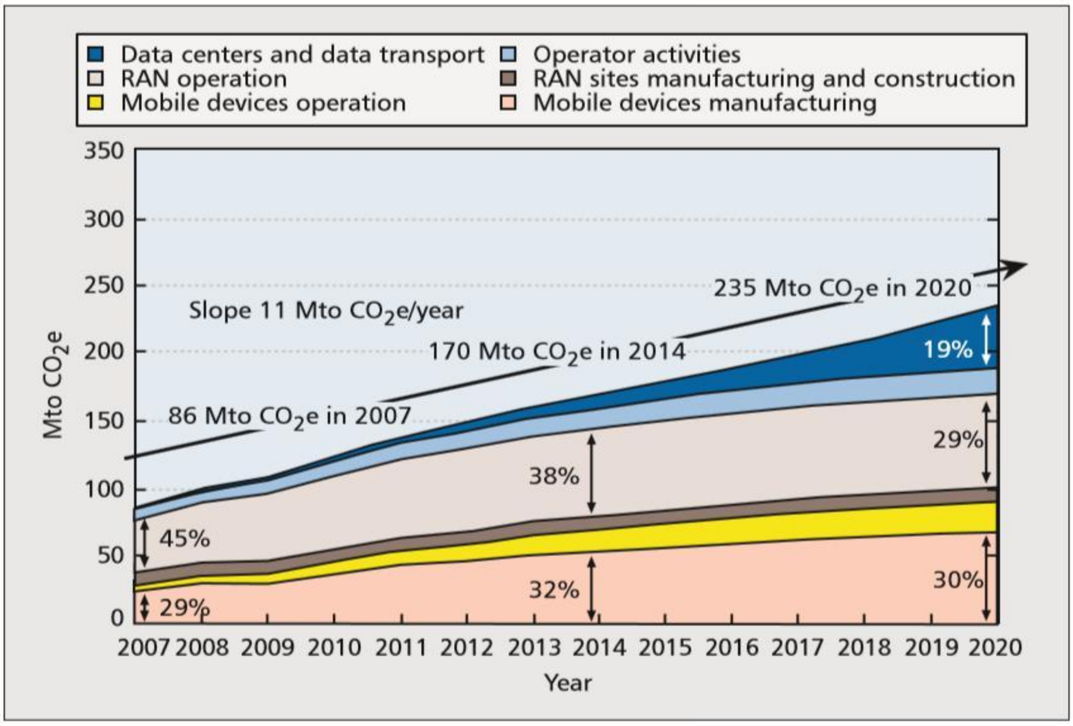


Figure 4: Global carbon footprint of mobile communications up to 2020 (Fehske A, 2011).

Figure illustrates emission from data centres and data transport, RAN operation, mobile device operation, operation activites, RAN sites manufacturing and construction, mobile devices operation. The graph illustrates the calculated carbon dioxide equivalent in metric tone and projected value if the trend remains same.

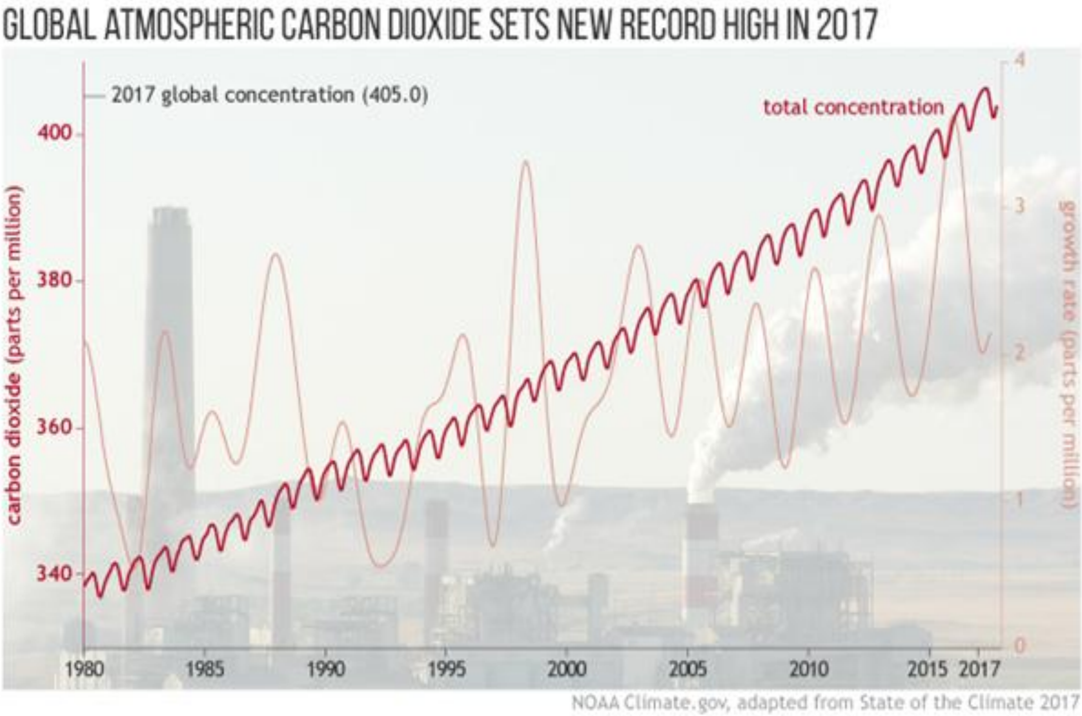


Figure 5 : Global Atmospheric carbon dioxide growth rate (NOAA Climate.gov,2017)

Above graph illustrates, global atmospheric carbon dioxide that sets new record high in 2017 in parts per million.

The European Union (EU) funded project Energy Aware Radio and Network Technologies (EARTH) for Energy Efficiency Evaluation Framework (E^3F) focused on the BS power consumption primarily builds on the radio network assessment methodology developed in the Third Generation Partnership Project (3GPP); the most important addenda are a sophisticated power model for various Base Station (BS) types, as well as a large scale long-term traffic model that allows for a holistic energy efficiency analysis over large geographical areas and extended periods of time. Then the E^3F is applied in order to provide an assessment of the BS energy efficiency of a 3GPP Long Term Evolution (LTE) network deployed within a representative European country. The calculated energy efficiency of LTE is compared to that of already deployed networks. One of the key findings of "the EARTH energy efficiency analysis is that on average the vast majority of the resources are idle, a fact that has been verified recently by measurements on a real 3G network in a major European city. Unfortunately, it is at low loads where the energy efficiency of contemporary systems such as LTE is particularly poor. This highlights the need to reduce the BS power consumption particularly at low network loads". (Auer, 2011)

"Mobile subscriber base crossed 5 billion mark in July 2010 and expected to cross 8 billion by 2020" (Lorincz, 2012). With increasing demand for telecom services, the energy consumption has also grown significantly and poses an environment challenge in terms of larger carbon emission footprint of the telecommunication industry. "The total global carbon footprint of the ICT industry as a whole is in the order of 860 million tonnes CO_2 which is approximately 2% of the global emissions. Of this, the contribution from global telecommunication systems-mobile, fixed and communication devices are around 230 million tons of CO_2 emission i.e. approximately 0.7% of global emissions". (GSMA, 2011)

India has around 310 thousand telecom towers, of which 70% are in rural areas. Presently 40% power requirements are met by grid electricity and 60% by diesel generators. The diesel generators are of 10-15 KVA capacity and consume about 2 liters of diesel per hour and produce 2.63 kg of CO_2 per liter. "The total consumption is 2 billion liters of diesel and 5.3 million liters of CO_2 is produced. For every kWh of grid electricity consumed 0.84 Kg of CO_2 is emitted. Total CO_2 emission is around 5 million tons of CO_2 due to diesel consumption and around 8 million tons due to power grid per annum". (GSMA,2011)

2.8 Reducing costs and pollution in cellular networks

Cellular wireless networks are expected to provide high quality audio and video services while enabling fast and low cost Internet access to mobile users. The need for green cost efficient networks is twofold: (*i*) reduce the service price, and (*ii*) preserve the environment. In this work, we discuss the various strategies that help reducing infrastructure costs, power costs, and GHG emissions with no impairments on the quality of network services. These strategies range in a wide area from enhancing the electronics, to developing new energy-aware radio access protocols, to deploying enhanced base stations with tunable capacity. To reduce both capital and operational expenditures, and to reduce the GHG footprint, the manufacturers propose new compact installation with lightweight antenna systems and very efficient power amplifiers that allow to save up to 50% of energy. Furthermore, manufacturers claim that using radio and computational resources efficiently might easily turn in a 40% drop in the operational costs. Recent scientific publications confirm that a very high gain could be achieved by optimizing the use of base stations proactively, and huge additional improvements could be obtained by optimizing power saving mechanisms by leveraging traffic statistics.

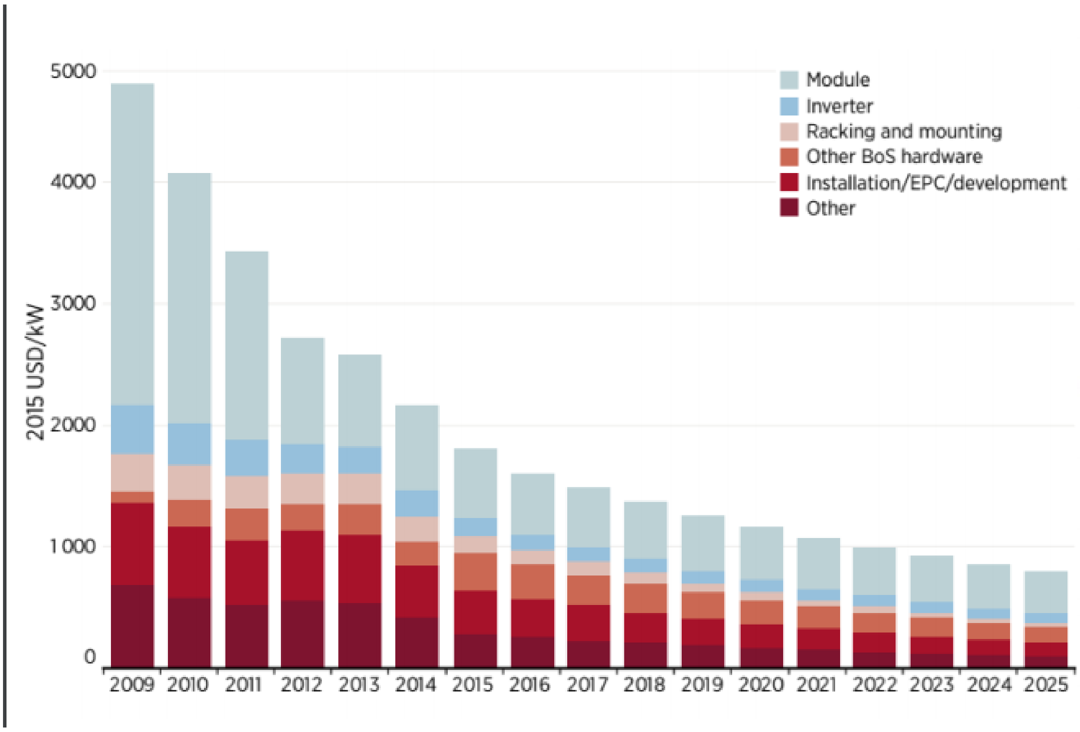


Figure 6 : Falling Prices of Solar PV and Wind Systems (IRENA ,2016)

The falling prices of PV and Wind systems has also raises the use of renewable powered BTS.

2.9 Renewable Energy Technologies Options

Renewable energy is referred to as the energy that can be repeatedly replenished. They are eco-friendly and sustainable energy sources, which is called green energy. According to International Energy Agency (IEA), "Renewable Energy is derived from natural processes that are replenished constantly". In its various forms, it derives directly or indirectly from the sun, or from heat generated deep within the earth. It is widely believed that the use of green energy is the most effective method for improving the overall environment. "Currently, around 16% of global final energy consumption comes from renewable energy with around 18% of green energy. Among a variety of green energy sources, wind power grows rapidly at the rate of 30% annually, which achieved 198GW all over the world and cumulative global photovoltaic installations surpassed 40GW at the end of 2010". (World Energy Outlook, 2010) In the past, power generators have been using diesel engines, while the current trend is towards the replacement of diesel with bio-fuels, and traditional generators with solar-or-wind powered generators. "Fuel cells are being installed as a standalone solution replacing the existing diesel generator. In a limited number of cases where electrical grid availability is close to 20 hours a day or more, the diesel generator at the tower site has been replaced completely by enhancing the existing battery capacity leading to improvement in economics and reduction of carbon emissions on site". (Singh, 2012)

In 2015, Nepal and the World Bank signed an agreement to invest USD 130 million to develop a 25 MW solar project that will eventually be connected to the national grid. It is the largest renewable energy plant planned in the country. (Himalayan Times, 2017)

2.9.1 Solar Photovoltaic (PV) Technology

Solar PV cells are solid-state semiconductor devices with no moving parts that convert sunlight into direct-current electricity. When light strikes their surface and they absorb photons of radiation in the visible of the electromagnetic spectrum. Each photon of light energy is absorbed by an electron within the solid material. In absorbing the energy, the electron acquires an electrical potential. This potential can be made available as electrical energy.

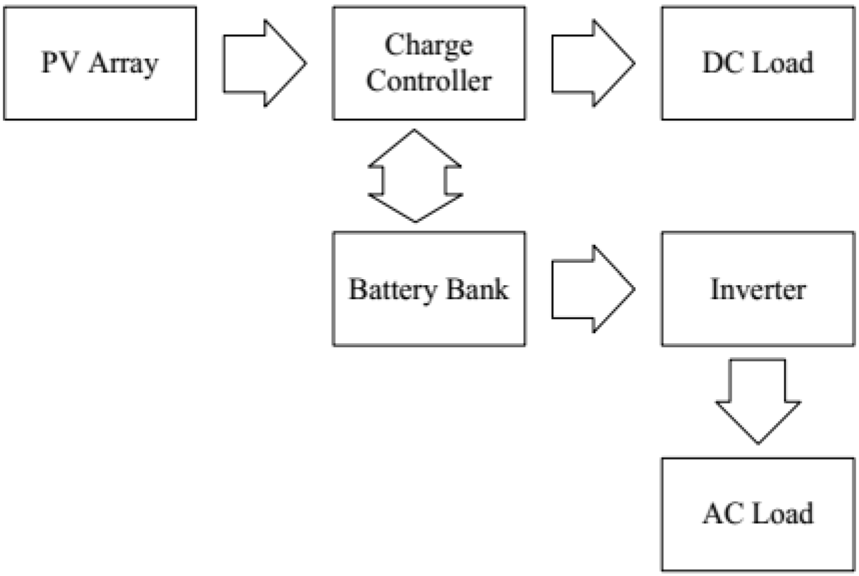


Figure 7 : Basic Solar PV System Design for Telecom Towers

2.9.1.1 Past Solar Energy Assessment

2.9.1.1.1 Seasonal Mean Solar Assessments

Nepal is characterized by a very complex topography which clearly influences surface Solars. High mountain chains located on the northern belt (Himalayan and Hilly belt) are characterized by relatively high-speed Solar and RegcM4.6 estimates average mean solar radiation in all seasons.

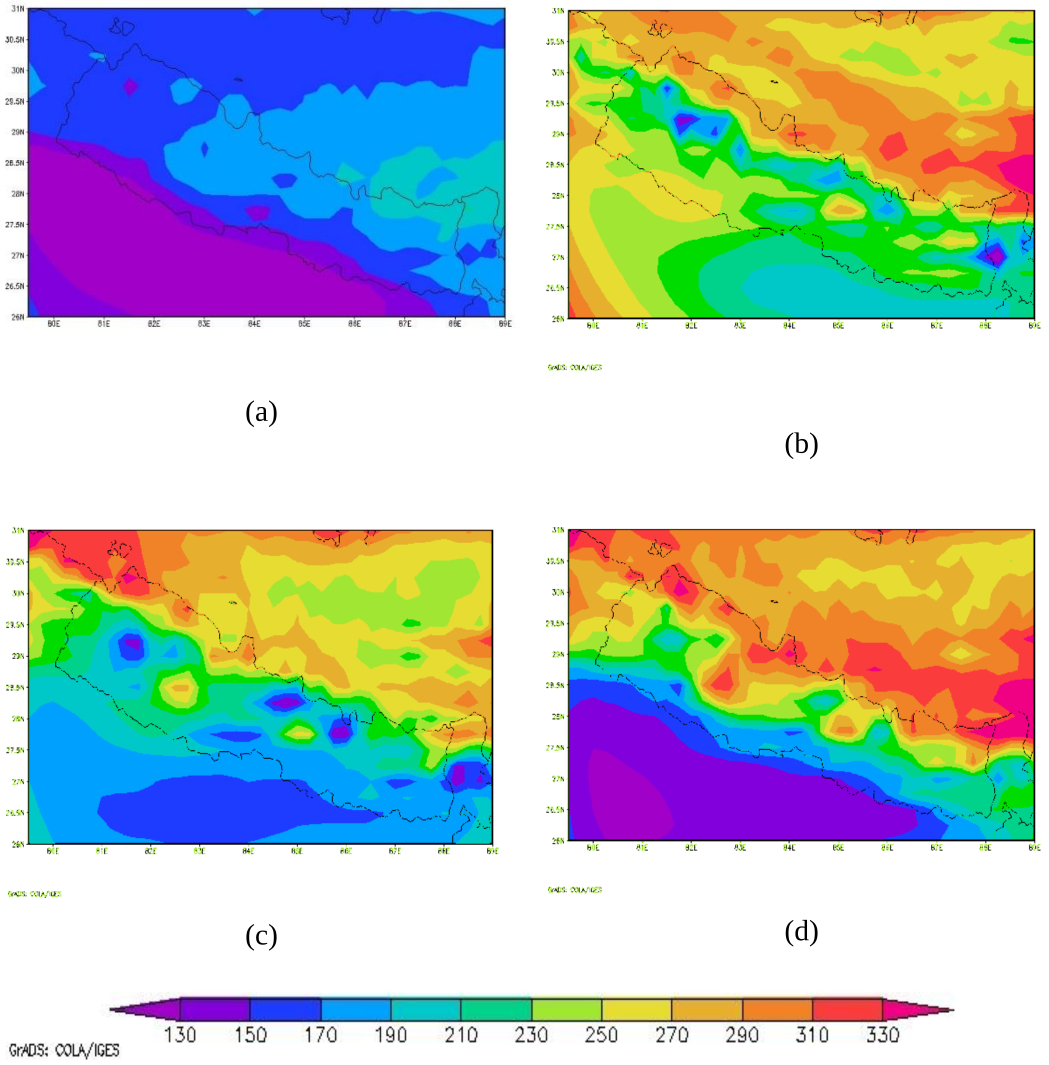


Figure 8 : Average solar power at 10-min (a) winter season, (b) spring season, (c) summer season, and (d) autumn season over historic period (1990-2010). (Prem,2018)

Figure 8 illustrates the average Solar radiation for four-season; winter (December, January and February), spring (March, April and May), summer (June, July and August) and autumn (September, October and November) over historic period 1991 to 2010. The solar radiation seems to be high in the Himalayan belt of Nepal than in hilly and terai belt. From figure 8 (a) shows the downscaled output of solar radiation in winter season, which depicts that the solar radiation is overall low than other season and the solar radiation is comparatively low in terai belt than hilly and Himalayan belt. The value of solar radiation is above than 150 W/m^2 and less than 210 W/m^{2}in hilly and Himalayan region where as in terai region the value is less than 150W/m^2. Figure 8(b) depicts the solar radiation during spring season. In this season also the trend is same from Himalayan to terai belt. But few location have the solar radiation high than other places. From figure apart from the Himalayan belt Kathmandu, Mechi, Nepalgung and Dhangadi has more solar radiation than other area. The value is in between 250 to 290W/m^2. During summer season the the solar radiation is high at Surkhet and Makwanpur than other place of Nepal after from the Himalayan belt where the solar radiation seems to be high in the North-East and North-West Corner of Nepal as shown in figure 8 (c).In the autumn season the solar radiation is high in Rukum, Dolpa and Jajarkot in western region and in Kathmandu, Bhaktapur, Nuwakot and Sindhupalchowk in Central region of Nepal as shown in figure 8 (d). In this season most of the part of Rukum, Dolpa and Jajarkot in western region have solar radiation value greater than 270W/m^2 whereas Bhaktapur, Nuwakot and Sindhupalchowk in Central region have value greater than 250 W/m^2.

2.9.1.1.2 Annual Solar Radiation Trend

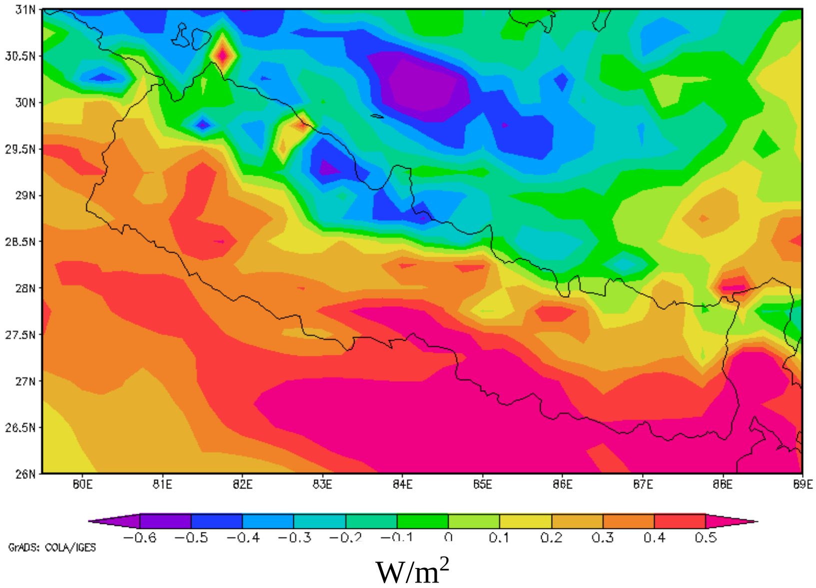


Figure 9: Annual Solar Radiation trend from 1990 to 2010 (Prem,2018)

The figure represents the Solar Radiation trend from 1990 to 2010 by RegCM. From the figure we can see that there were positive and negative changes on over past 20 years. There was increased trend in Hilly and Terai belt while there was decreased trend in upper hilly and Himalayan belt. In terai belt, there was high increased average Solar radiation at rate more than 0.3 W/m^2 per year.

2.9.1.2 Future Solar Radiation Pattern

2.9.1.2.1 Future Seasonal Solar Radiation Pattern

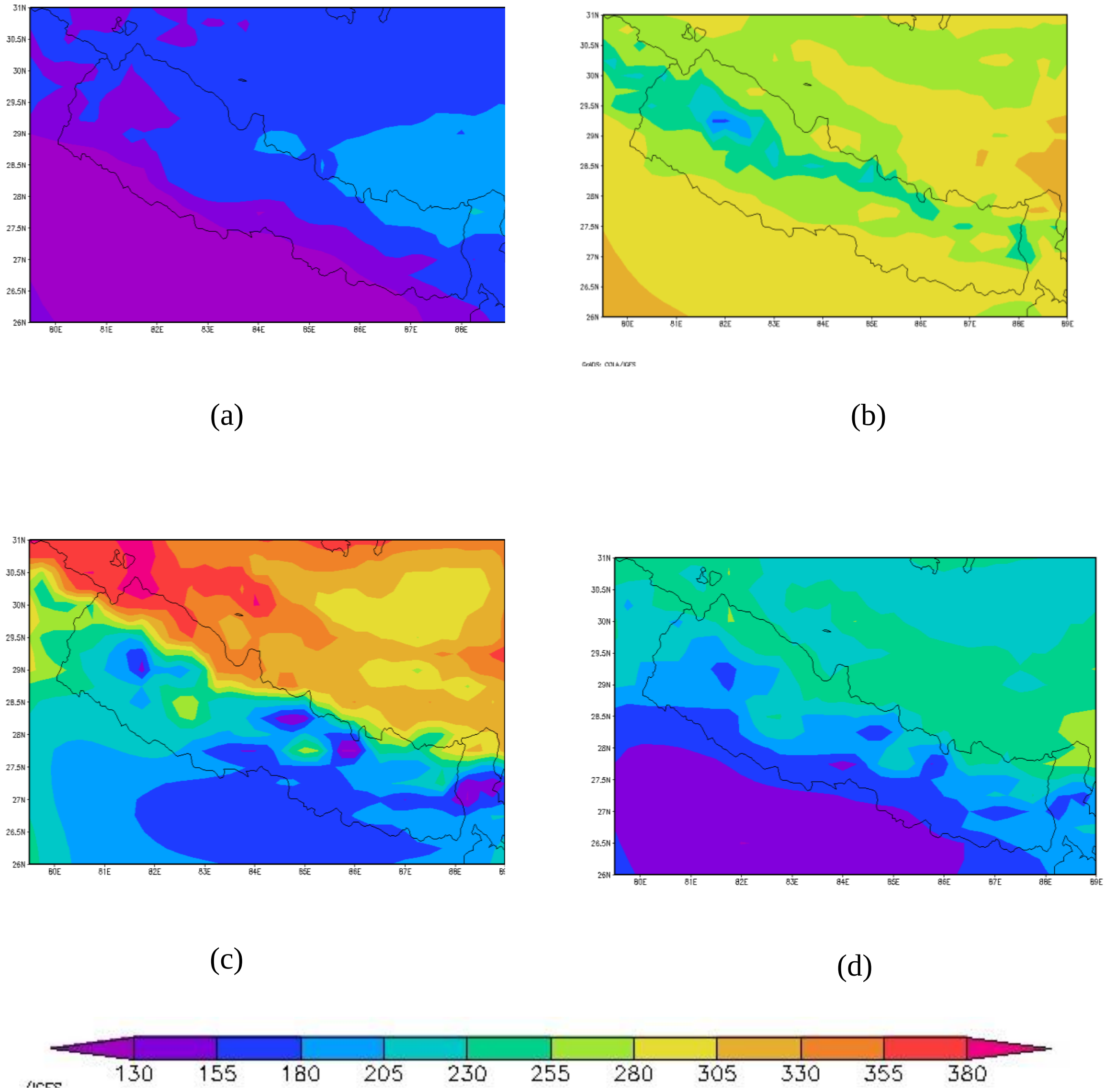
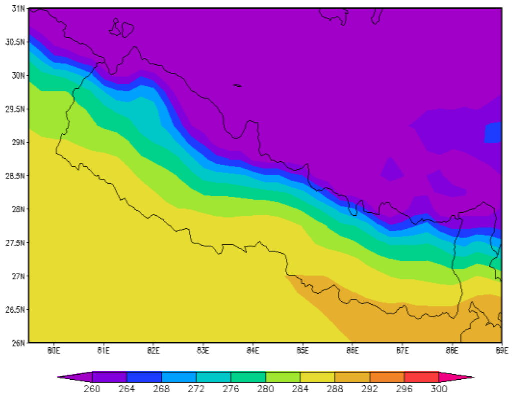


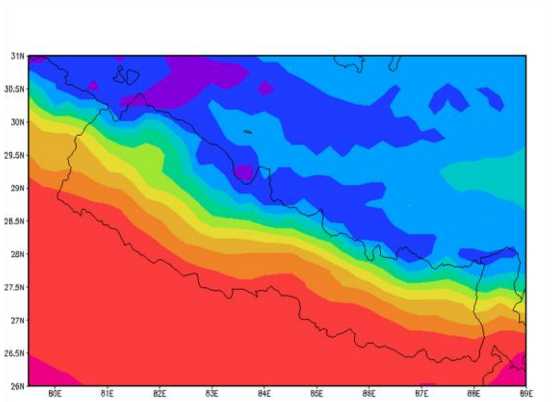
Figure 10: Future Solar Radiation(a) winter season, (b) spring season, (c) summer season, and (d) autumn season over historic period (2030-2050). (Prem,2018)

Figure 10 illustrates the Solar radiation for four-season; winter (December, January and February), spring (March, April and May), summer (June, July and August) and autumn (September, October and November) for future duration from 2030 to 2050. The solar radiation seems to be high in the Himalayan belt of Nepal than in hilly and terai belt. From figure 10 (a) shows the downscaled output of solar radiation per year in winter season, which depicts that the solar radiation is overall lower than other season and the solar radiation was comparatively low in terai belt than hilly and Himalayan belt. The value of solar radiation is above than 155 W/m^2 and less than 205 W/m^2 in hilly and Himalayan region where as in terai region the value is less than 155 W/m^2. In hilly region, Bajura Kalikot, Achham and Dailekh have solar radiation less than 155 W/m^2. Figure 10 (b) depicts the solar radiation during spring season. In this season the trend is different from Himalayan to terai belt. The radiation is in decreasing fashion from terai to Himalayan belt. In terai to mid hilly region value is in between 255 to 305 W/m^2. In the upper part of Gorkha, Rasuwa and Sindhupal chowk the value is in between 205 to 230 W/m^2. During summer season as shown in figure 10 (c) the future solar radiation variation is not in definite pattern. The value in terai and hilly region is less than 205 W/m^2. However Rukum, Rolpa and Kathmandu have value more than 280 and less than 305 W/m^2. In the autumn season the future solar radiation is less than 230 W/m^2. At few places of Humla and Taplejung the value is between 280 to 305 W/m^2 as shown in figure 10 (d).

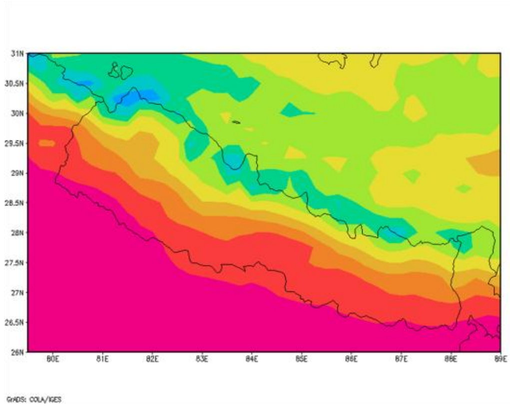
2.9.1.2.2 Future Seasonal Temperature Pattern



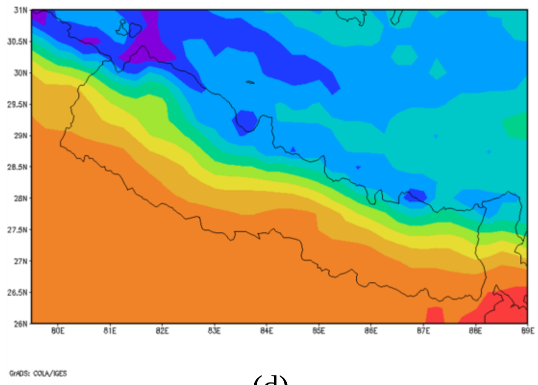
(a)



(b)



(c)



(d)

Figure 11 : Future Temperature Trend (a) winter season, (b) spring season, (c) summer season, and (d) autumn season over historic period (2030-2050).(Prem,2018)

Yearly average maximum ground solar radiation is also predicted to increase 0.8W/m^2 per year at Dolpa and Mugu in future 2030-2050, whereas for the present base year 1990 to 2010 the increasing rate is 0.3W/m^2 per year and it is 0.4W/m^2 per year at few places.

Photovoltaic electricity generation depends on solar irradiance, and other atmospheric variables affecting panel efficiency, such as surface air temperature. In this research, surface air temperature and solar radiation were generated by using RegCM 4.4 with the resolution of 20 km x 20 km. The model was used to downscale past climate of 1990-

2010 using Era interim reanalysis data. Further it was used to downscale the temperature and solar radiation data for time period of 2030-2050 using HadGEM2 General Circulation Model output of scenario RCP4.5 which was developed by Hadley Centre.

The future seasonal variation of temperature, solar radiation and were analyzed for four seasons. The maximum average temperature is projected to be around 300K in Terai region in future for the time period of 2030-2050; it will be high in the summer season. Humla, Mugu and few parts of Dolpa near to Mustang seem to have decreasing trend of temperature in future and the value is -0.03 to -0.12K/year. Whereas in the base year 1990 to 2010 the trend of temperature variation is in increasing by more than 0.02^0C/year in Terai, while in North-West corner and some part of dolpa and mustang the temperature is in decreasing trend by -0.02^0C/year and -0.04^0C/year respectively. In the base year 1990-2010, the maximum average solar radiation is found to be 220W/m^2 in high in North-West part of Nepal and during that period the maximum annual trend of solar radiation is increasing by 0.3W/m^2 per year whereas in the future 2030 to 2050 the value is found to be 0.8W/m^2 per year at Dolpa and Mugu. The efficiency of the cell is found to be 16.5% in the Himalayan region in comparison to 11% in Terai belt.

This research has found that mean surface air temperature is predicted to increase in the near future, i.e. 2030-2050. The predicted mean temperature increasing rate is 0.03K per year, which is an increase of 50% from the base year period of 1990-2010. There is an increase of 166.67% on ground solar radiation trend per year in future than the base year.

Considering high concentrating solar radiation is required for power generation from the CSP (Concentrated Solar Power), area under average annual irradiance is greater than 5.5 kWh/m^2/day is taken which is about 2729 km^2. “Typical solar trough technology produces 33.5 MW peak per sq.km of land area. If only 2% of the best solar irradiance is taken for the power generation, it can yield 1829 MW which is more than the present power demand 912 MW of Nepal” (NEA, 2007). “If cost for building such plants comes at competitive price then there will be huge demand for solar energy for the coming year and that will also enhance in clean energy development”. (SWERA, 2008)

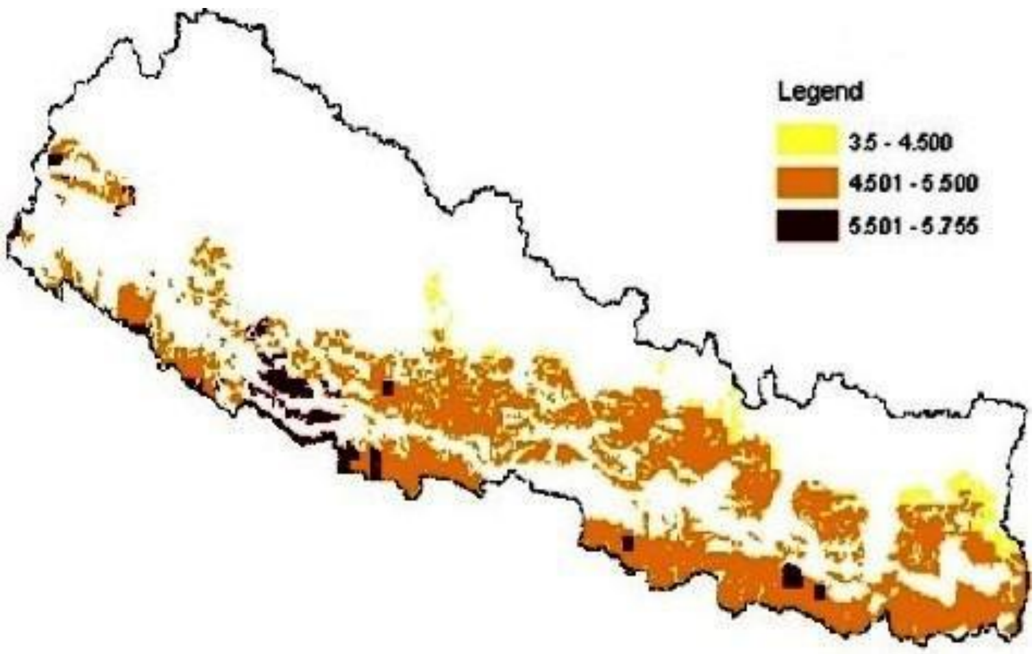


Figure 12 : Concentrated Solar Power Potential of Nepal in kWh/m^2/day

S.N.	Solar Radiation Class (kWh/m^2/day)	Average Annual Radiation (kWh/m^2/day)	Area (km^2)
1	3.5-4.5	4.16	2174.49
2	4.5-5.5	5.22	32587
3	5.5-5.75	5.561	2729.53
	Total	14.941	37491.02

Table 2 : Area under Different Annual Direct Normal Radiation in Nepal

Since a PV system can only generate power during sunshine hours, it is not feasible to create a standalone solution for telecom towers. Generally, a SPV backup power system is designed with a combination of appropriate sized battery banks, or used to offset the operation of a backup power system like a diesel generator for approximately four hours per day when sunlight is available.

2.9.2 Wind Power

Wind energy is also a form of solar energy because wind is the movement of air in response to pressure differences within the atmosphere and such pressure differences are caused primarily by differential heating effects of the sun on the surface of the earth. Wind has considerable potential as a global clean energy source, being both widely available, though diffuse, and producing no pollution during power generation.

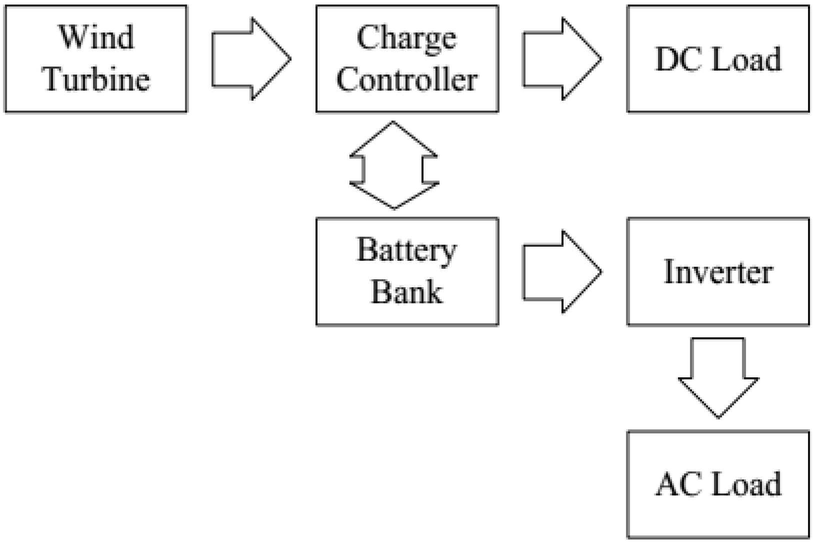


Figure 13 :Basic Wind Power Schematic for Telecom Tower

For wind power, wind turbine attached to an electrical generator converts wind power to electrical energy and they can be stored in lead-acid batteries, as direct current. “Globally, wind power production quadrupled from 2000 to 2006. It accounts for 20% of electricity use in Denmark, 9% in Spain, and 7% in Germany”. (Okundamiya, 2014)

Wind energy constitutes one of the main alternatives for facing the energy problems of the future, taking into account the foreseeable depletion of the fossil fuels. As wind isn’t steady source, meteorological factors and topography affects wind that leads to significant daily and seasonal variations. This research was done to study the impact of climate change on wind energy potential of entire Nepal. In this research, RegCM-4.6 regional climate model was used to downscale the EIN15 reanalysis data to a resolution of 20 km x 20 km. For future projection of wind energy, HadGEM2-ES data of RCP4.5 emission scenario was downscaled at the resolution of 20 km x 20 km for time period of 2030-2050.In order to assess the wind energy potential in Nepal for past 20 years, the seasonal average wind speed, 5-year interval annual wind speed and wind power density at 10m, 50m, 80m and 100m, were analyzed. The output shows the Humla, Dolpa, Mugu, Manang, Mustang, Rolpa, Salyan, Dang, Kathmandu, Dhading and Solukhumbu district had higher potential of the wind energy. In winter and spring season there was comparatively higher average wind speed than summer and autumn season. There was increased trend in Hilly and Terai belt while there was decreased trend in Himalayan belt over past 20 years. The model projects the lesser wind energy potential in most district of Himalayan bel in all seasons for period 2030 to 2050. The model estimates the wind speed of 5 to 6m/s in Himalayan belt district like Dolpa, Mugu, Mustang, Solukhumbu and Taplegunj. In Humla and Mugu district, the model presents the high increasing trend while in Mahottari and Dhanusha district, there is decreasing trend. (Maharjan,2018)

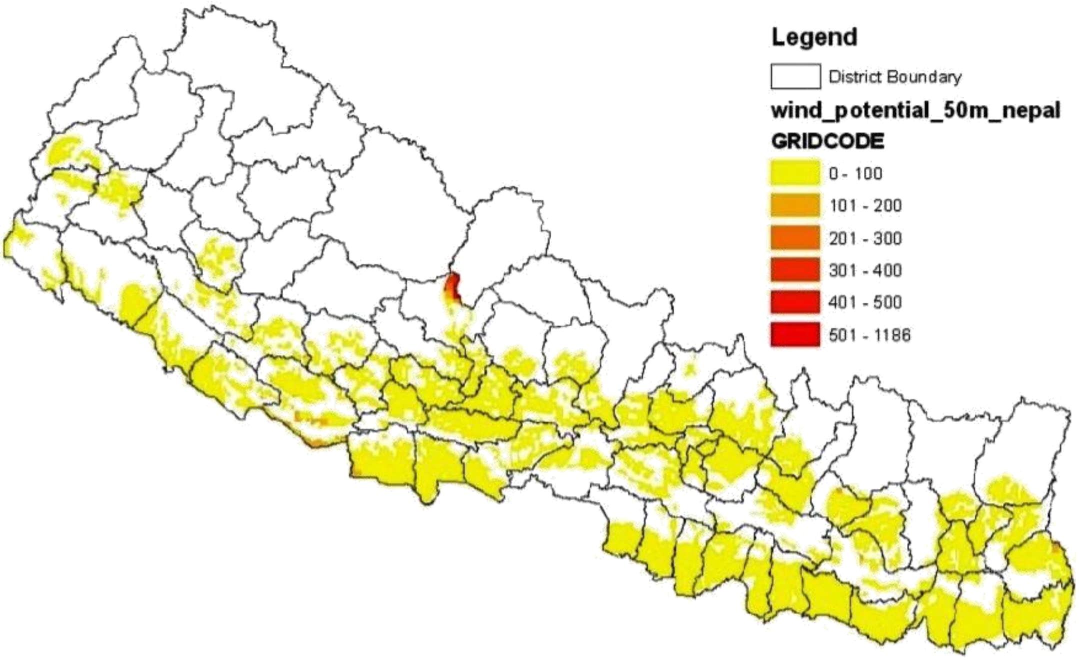
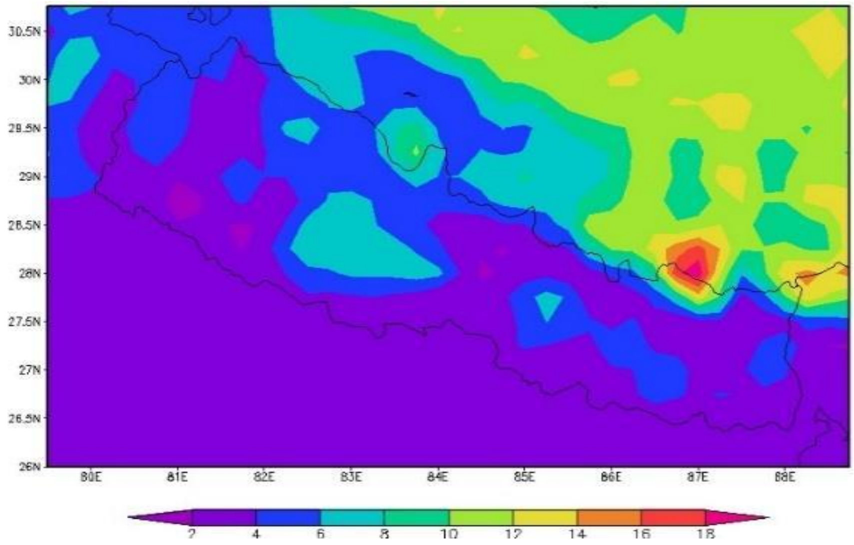


Figure 14 : Wind Power Potential of Nepal

2.9.2.1 Seasonal Mean Wind Assessments

Nepal is characterized by a very complex topography which clearly influences surface winds. High mountain chains located on the northern belt (Himalayan and Hilly belt) are characterized by relatively high-speed wind and RegcM4.6 estimates average mean speed in all seasons.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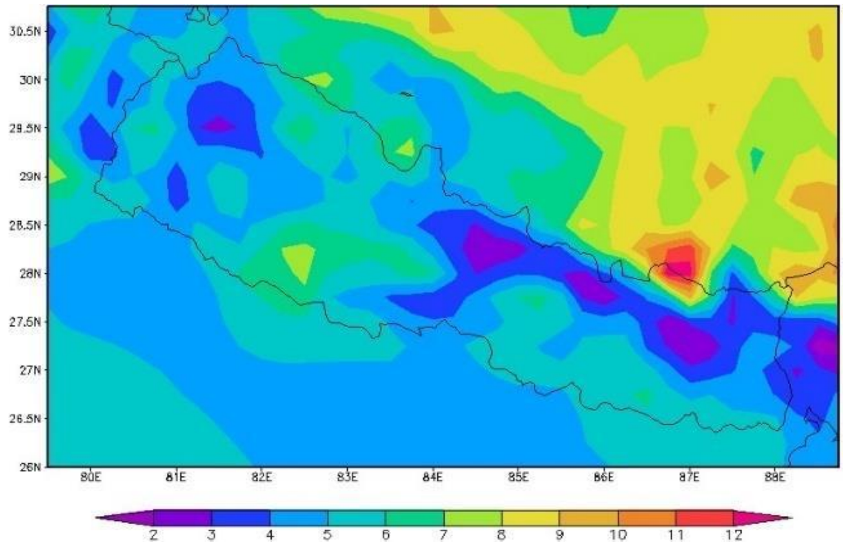
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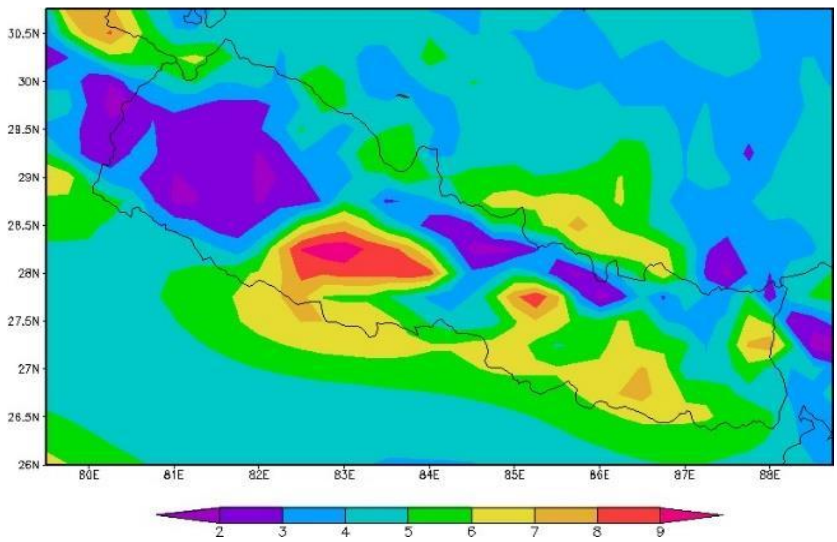
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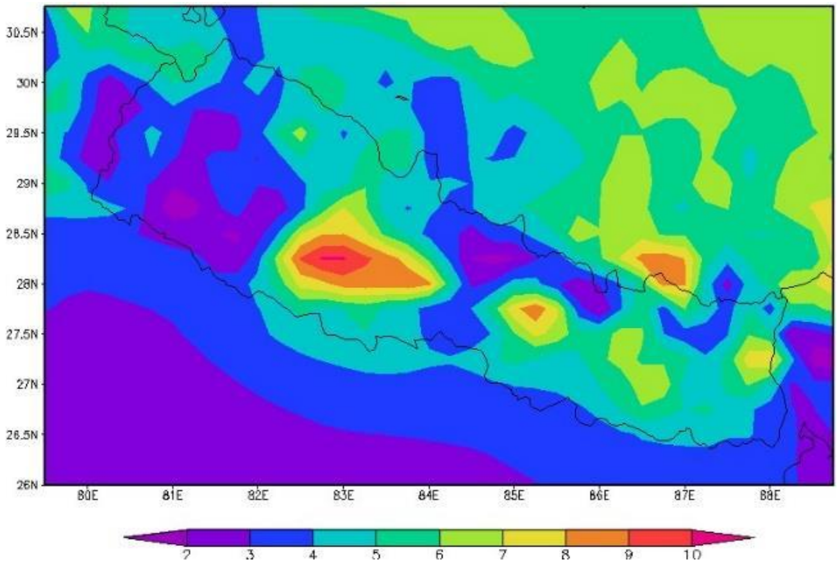


d)

Figure 15 : The climatological average wind speed at 10 m agl in (a) Winter season, (b) Spring season, (c) Summer season, and (d) Autumn season to the Future period 2031 to 2050 under the RCP 4.5. (Maharjan,2018)

The figure 15 presents the projected seasonal wind energy potential (WEP) of Nepal to the future period 2031 to 2050 at 10 m above ground level. The WEP in different location has been projected on basis of emission scenario RCP4.5 which is based on the same population and income drivers and applies greenhouse gas emissions evaluation policies to stabilize atmospheric radiative forcing at 4.5 W/m^2 in 2100. The WEP pattern forecasted by the RegCM shows the strongest wind speed of 16 m/s in Solukhumbu district in winter season. In spring and autumn season, model shows more than 7 m/s wind speed but in summer season there is only 5 m/s in Solukhumbu district. The model simulates the good wind speed in Terai belt in spring, summer and autumn season t. The model projects the lesser WEP in most district of the Himalayan belt in all season.

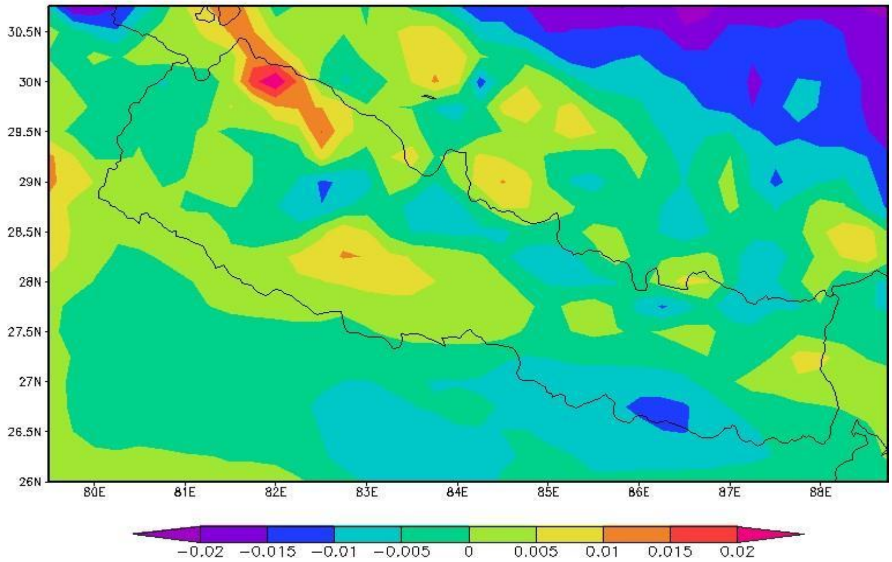


Figure 16: Annual wind speed trend from 2030 to 2050 (Maharjan,2018)

The figure illustrates the annual wind speed trend from 2030 to 2050. From the figure we can see that there are positive and negative changes in nearby future. There is increased trend in some district like Humla, Mugu, Dolpa, Manang and Solukhumbu while there is decreased trend in other districts of Himalayan belt. In Western, Mid Western and Far-Western Region of Terai belt, there is increased average wind velocity at 10 m from average ground level while in central and eastern region of Terai belt, there is decreased trend. In Humla and Mugu district, the model presents the high increasing trend while in Mahottari and Dhanusha district, there is decreasing trend.

A potential of about 200 MW wind power in the 12 km corridor from Kagbeni to Chhusang generating about 500 GWh electricity annually has been identified so far in Nepal (Dangrid 1992). Similarly, another study undertaken in Solukhumbu district in 1997 reveals that “the average wind speed in the Khumbu region is 5m/s and is suitable for electricity generation”. (GEMP-RED, 2000).

Wind Power Density	Average Wind Power Density	Area (km^2)	Wind Power Potential @ 5MW/km^2
<100	25	37178.08	-
100-200	124	449.86	-
200-300	217	27.74	-
300-400	353	21.99	109.95
400-500	473.5	31.74	158.7
>600	819.25	44.07	220.35
	Total	37753.48	489

Table 3 : Area under Different Wind Power Density of Nepal (Maharjan,2018)

Wind power density (WPD) less than or equal to 100 Watt/m^2 are not useful for wind energy harnessing. WPD greater than 200 Watt/m^2 are normally taken for consideration for non-grid connected power generation while greater than 300 Watt/m^2 are considered as grid connectivity wind energy in developing countries.

The analysis shows area above 300 Watt/ m^2 composed of 97 km^2 and with 5 MW installed per km^2, yields 489 MW. These areas have been calculated on a conservative basis so that the exploitable area for wind energy can be increased by covering greater area from the national grid and specially analyzed in specific areas with greater wind energy potential (SWERA, 2008).

2.10 Model of wind turbine

Using the wind speed at a reference height hr from the data base, the velocity at a specific hub height for the location is estimated on an hourly basis throughout the specified period through the following expression.

$$v(t) = v_r(t) . \left(\frac{h}{h_r} \right)^{\gamma} \quad \text{.................................(1)}$$

where v is the wind speed at projected height h,$v_r$is wind speed at reference height $h_r$and γ is the power-law exponent (~1/7 for open land). In function of this wind speed, the model used to calculate the output power, P_{WT}(t) (W), generated by the wind turbine generator is as follows:

$$P_{WT}(t) = \begin{cases} a.v^3(t) - b.P_R & v_{ci} < v < v_r \\ P_R & v_r < v < v_{co} \\ 0 & otherwise \end{cases} \quad \text{..............................(2)}$$

$$a = P_R / (v^3_r - v^3_{ci}),\ b = v^3_{ci} / (v^3_r - v^3_{ci}), \quad \text{..............................(3)}$$

$P_R$is the rated power, v_{ci}, v_r and v_{co} are respectively the cut-in, rated and cut-out windspeed. (Belfkira,2009)

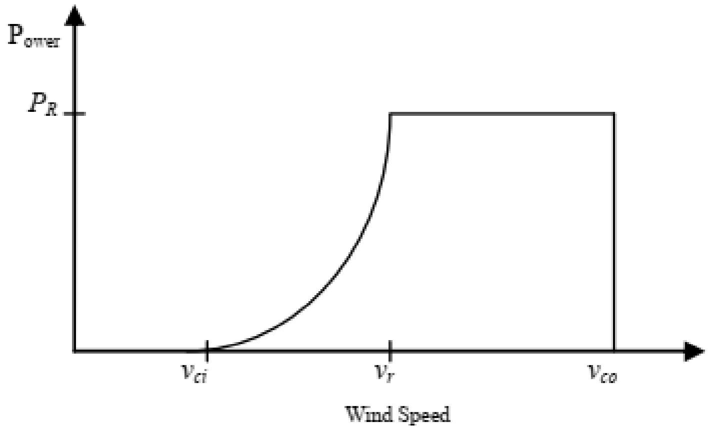


Figure 17 : Typical wind turbine characteristics of the wind turbine.

2.11 PV array modelling

The output power from a PV panel can be calculated by an analytical model given by France Lasnier and Tony Gan Ang, which defines the current-voltage relationships based on the electrical characteristics of the PV panel. This model includes the effects of radiation level and panel temperature on the output power. With a maximum power point tracker (MPPT), the output power from a PV panel is given as:

$$\begin{cases} P_{PV}(t) = V_{mpp}(t).I_{mpp}(t) \\ V_{mpp}(t) = V_{mpp,ref} + \mu_{V,oc}\left(T_c(t) - T_{c,ref}\right) \\ I_{mpp}(t) = I_{mpp,ref} + I_{sc,ref}\left(G_T(t)/G_{ref}\right) + \mu_{I,sc}\left(T_c(t) - T_{c,ref}\right) \end{cases} \quad \text{…………...…(4)}$$

where $P_{PV}$is the PV panel power at the maximum power point (W), $V_{mpp}$is the PV panel voltage at the maximum power point (V), $V_{mpp\ ,ref}$is V_{mpp}at reference operating conditions (V), $I_{mpp}$is the PV panel current at the maximum power point (A), $I_{mpp,ref}$ is I_{mpp} at reference operating conditions (A), $I_{sc,\ ref}$is the short circuit current at reference operating conditions (A), $G_T$is the hourly irradiance on a tilted surface (W/m²), $G_{ref}$is the irradiance of 1000 W/m² at reference operating conditions, $\mu_{V,oc}$and $\mu_{I,sc}$are the temperature coefficients for open circuit voltage (V/°C) and short circuit current (A/°C)respectively, *Tc,ref* is the PV panel temperature of 25°C at reference operating conditions and *Tc* corresponds to the PV panel operating temperature (°C), it can be expressed as follows

$$T_c(t) = T_a(t) + \frac{NOCT - 20}{800} \cdot G_T(t) \quad \text{……………………………(5)}$$

where *Ta*(t) is the ambient temperature (°C) of the site under consideration and *NOCT*(Normal Operating Cell Temperature) is defined as the cell temperature when the PV panel operates under 800W/m² of solar irradiation and 20°C of ambient temperature, *NOCT* is usually between 42°C and 46°C.Most local observatories provide only solar irradiation data on a horizontal plane. Thus, an estimate of the solar irradiation incident on any sloping surfaces, as analyzed by, is needed.The PV panels are connected in series to form strings, where the number of panels to be connected in series $N_{PV,s}$is determined by the selected DC bus voltage (U_{Bus}) as follows

$$N_{PV,s} = \frac{U_{Bus}}{U_{PV,nom}} \quad \text{……………………………(6)}$$

where $U_{PV,\ nom}$is the nominal PV panel voltage. Then $N_{PV,s}$ is not subject to the optimization, whereas the number of parallel strings $N_{PV,p}$is the design variable that needs optimization. (Belfkira,2009)

2.12 Modelling of battery

For the charging process and discharging process of the battery bank, the state of charge (*SOC*) can be calculated from the following equation

$$SOC(t+\Delta t)=SOC(t)+\eta_{bat}\left(\left(P_B(t)\right)/U_{bus}\right)\Delta t \quad \text{.................................(7)}$$

where $\eta_{bat}$is equal to the round-trip efficiency in the charging process and is equal to the 100% in the discharging process , $U_{bus}$is the DC bus voltage and Δt is the hourly time step is set equal to 1 hour. For longevity of the battery bank, the maximum charging rate, *SOCmax*, is given as the upper limit, where *SOCmax* is equal to the total nominal capacity of the battery bank, *Cn*, which is related to the total number of batteries, $N_{BAT,}$ the number of batteries connected in series, $N_{BAT,s}$ and the nominal capacity of each battery, $C_{B\,(\mathrm{Ah})}$, as follows:

$$C_n=\frac{N_{BAT}}{N_{BAT,s}}.C_B \quad \text{.................................(8)}$$

The lower limit that the state of charge of the battery bank does not have exceeded at the time of discharging is *SOCmin* which may be expressed as follows

$$SOC_{min}=(1-DOD).SOC_{max} \quad \text{.................................(9)}$$

where DOD is the Depth of Discharge of the battery.

The batteries are connected in series to give the desired nominal DC operating voltage and are connected in parallel to yield a desired Ah system storage capacity. Then, the number of batteries connected in series depends on the DC bus voltage and the nominal voltage of each individual battery $U_{bat\,,nom}$and it is calculated as follows

$$N_{BAT,s}=\frac{U_{bus}}{U_{bat,nom}} \quad \text{.................................(10)}$$

The number of batteries to be connected in series is therefore not subject to the optimization but is a straightforward calculation, whereas the number of parallel battery strings, each consisting of $N_{BAT,s}$batteries connected in series, is a design variable that needs optimization. (Belfkira,2009)

CHAPTER THREE: RESEARCH METHODOLOGY

This HOMER (Hybrid Optimization Model for Electric Renewables) is used as research tools in consecutive way. With subsequent review of various energy modeling tools, I found HOMER, the best to my purpose. It's been a great enthusiasm to use HOMER which prosper the scope of this study.

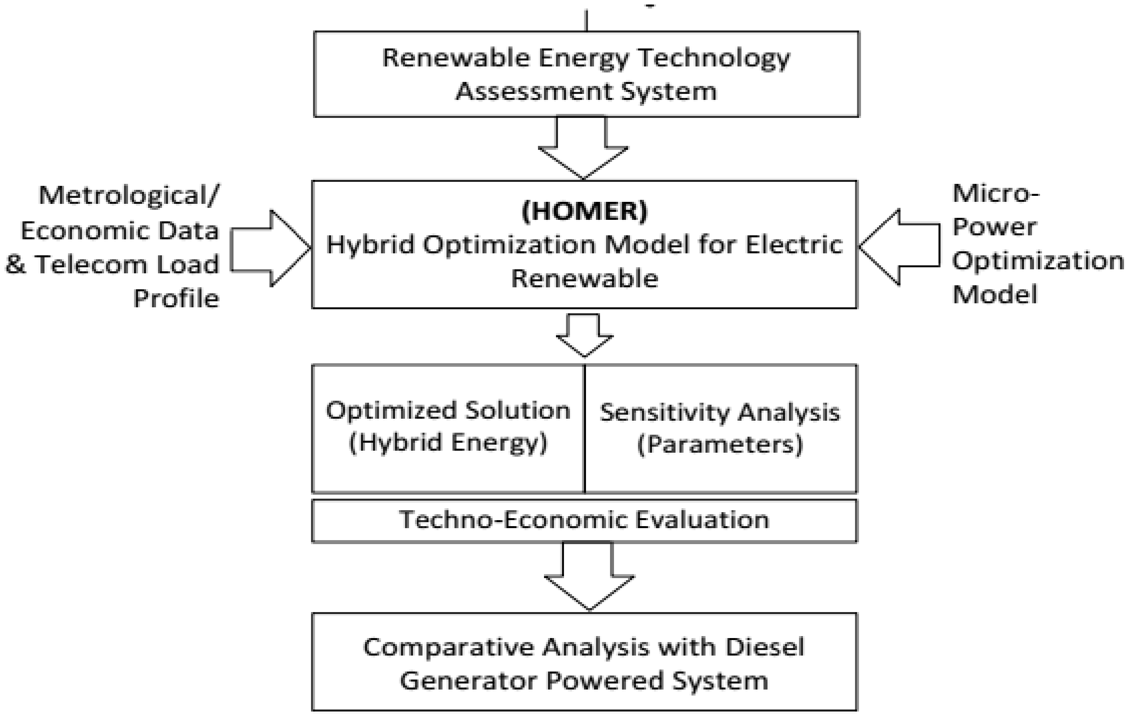


Figure 18: Strategic Framework Design (www.homerenergy.com)

3.1 RETs Assessment with HOMER

In this report, HOMER is used to assist in the design of powering telecom towers and to facilitate the comparison of power generation technologies based upon their technical and economic merits. The effects of uncertainty or changes in the inputs are analyzed and quantified through sensitivity analysis and optimized outputs. HOMER analysis starts up with some basic input parameters with sufficient data viability and ends with optimized output with significant economic and financial analysis as shown in Table 4.

HOMER Inputs	
Load	Telecom loads (BTS, VSAT & RS)
Resources	Solar, wind, diesel and temperature profile
Components	Solar PV, wind turbine, diesel generator, converter and battery
Decision Variables	Telecom loads, solar insolation and diesel price
Economics Parameters	Costs (capital, replacement, O&M), interest rate, project life time.
Other Parameters	Emission, System Control and Constraints

HOMER Outputs	
Simulation	Energy balance calculation, life cycle cost of the system, annual electrical energy production, state of charge of battery bank
Optimization	Feasible configuration with least lifecycle cost (size of PV array, wind turbine, batteries and generator) with dispatch strategy.
Sensitivity Analysis	Impact in cost of energy for the system with change in input variables.

Table 4: Input/output Protocols in HOMER (www.homerenergy.com)

3.2 Case Study

Since, HOMER requires relevant data as an important part to analyze, select and to design the system, all necessary data (meteorological, technical, economic) are taken from secondary source of information (previous reports and databases) that actually represents the real essence of this project. Furthermore, solar and wind resource data validation is assessed with NASA database.

3.2.1 Site Location

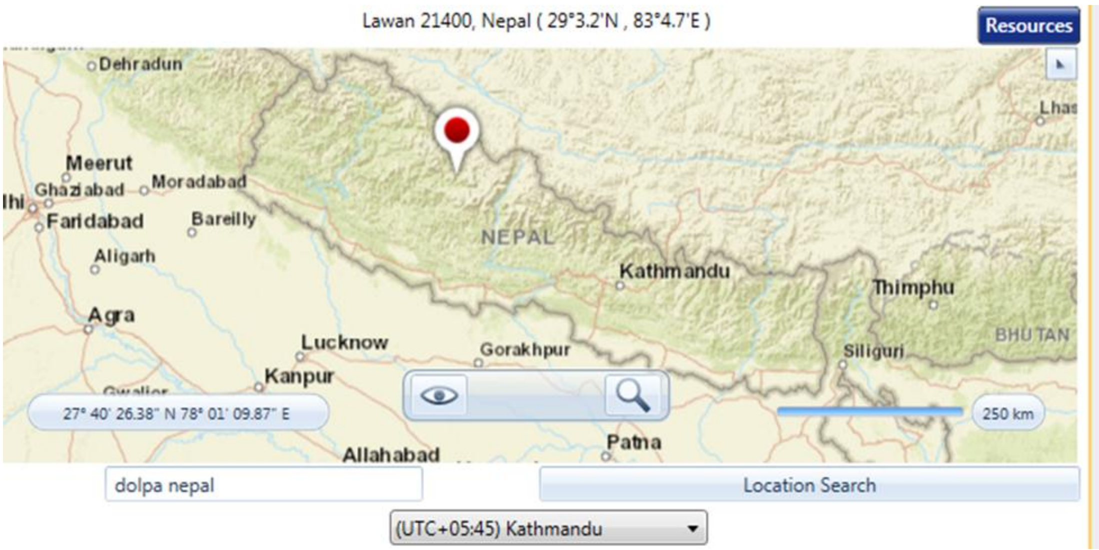


Figure 19: Site Selection (Dolpa District)

Dolpa is the largest district of Nepal covering 5.36% of the total landmass of the country, located at 28°43'N to 29°43'N latitude, and 82°23'E to 83°41'E longitude. Elevation ranges from 1,525 to 7,625 m (5,003 to 25,016 ft).

3.2.2 Energy Resource Profile and Telecom Load

With reference to the annual report of NT, telecommunication traffic in Nepal is very low at 1:00 am to 6:00 am and 11:00 pm to 12:00 pm. Therefore, BTS is operated at full load and half load condition under maximum and minimum traffic, hence the power consumption of BTS is categorized according to the time interval carried by the traffic.

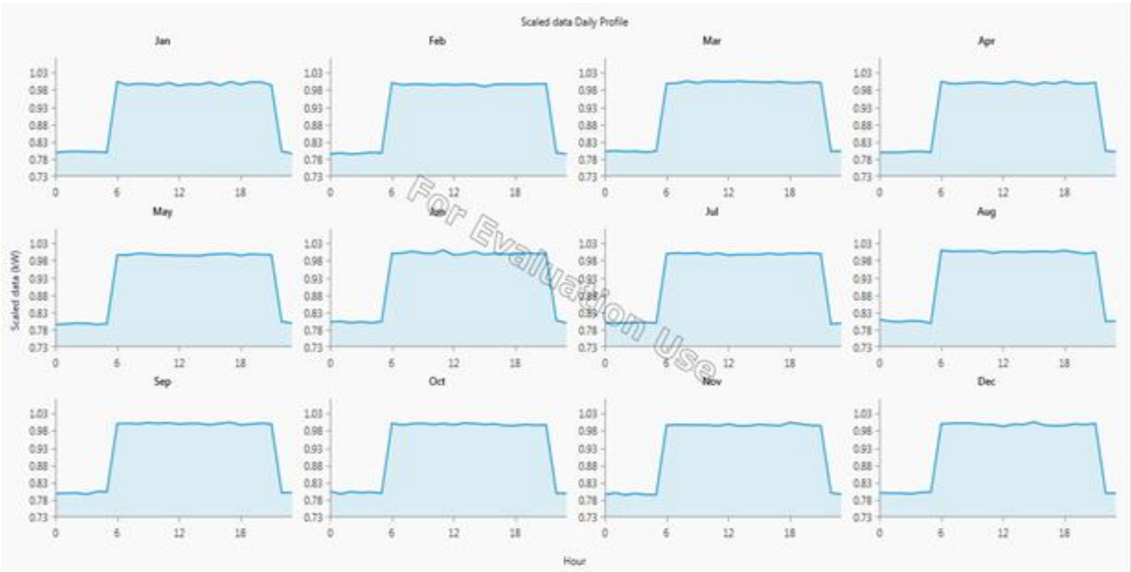


Figure 20:Hourly Telecom Load Profile for each month

The graph is of scaled data daily profile and scaled data (kW) of telecommunication traffic in Nepal. It represents the hourly profile for each month of a year and the profiles are assumed to be same for every month. Telecommunication traffic is very low from 1:00 am to 6:00 am and 11:00 pm to 12:00 pm.

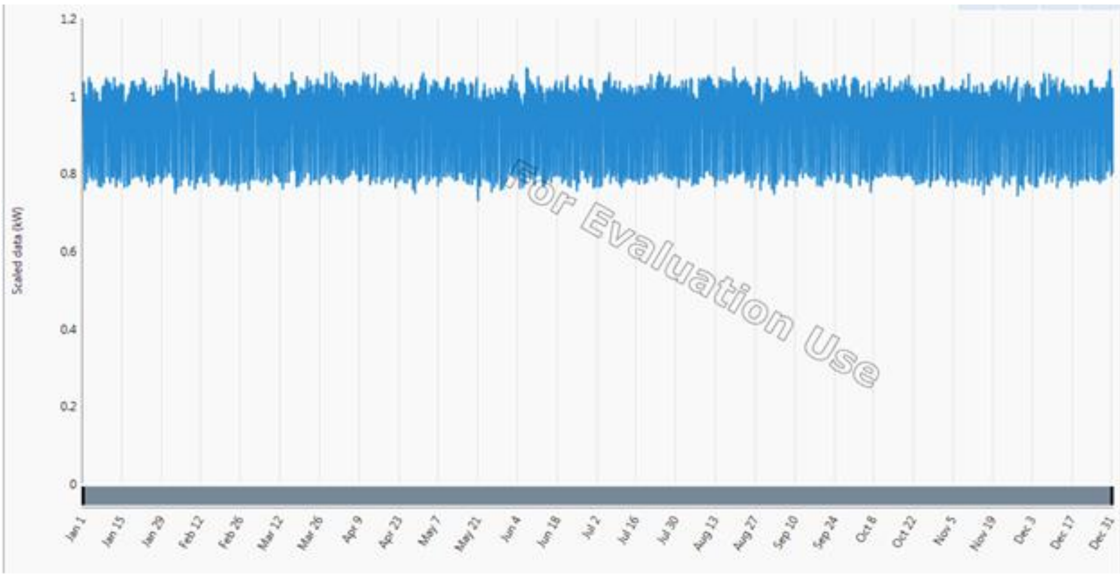


Figure 21:Daily telecom load profile

Above figure illustrates that every day scaled data vary between 0.8kW to 1.0kW

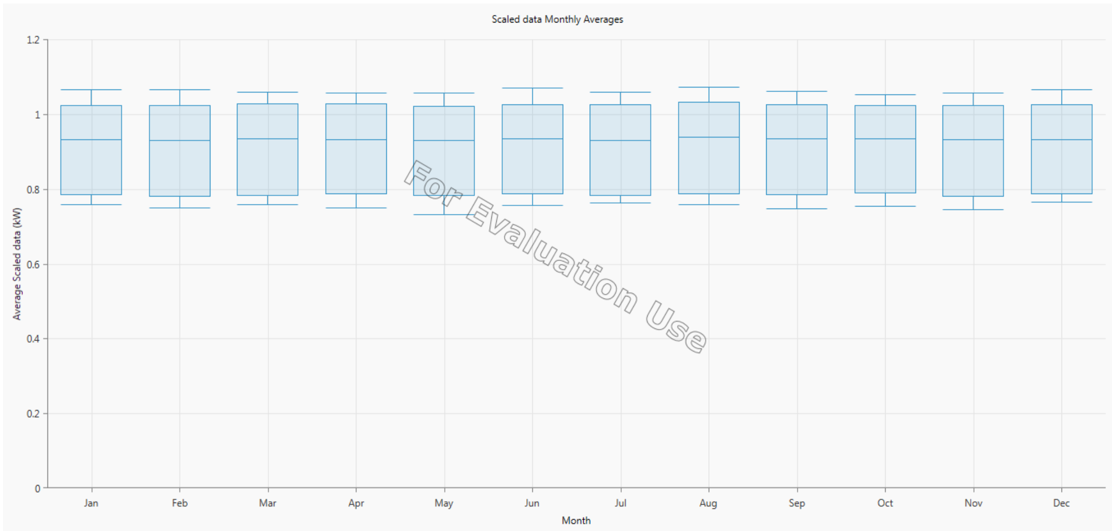


Figure 22 :Monthly Average Telecom Load plot

The box plot above shows the relation between average scaled data (kW) and scaled data monthly averages. Interquartile range is between 0.8kW to 1kW. Median value is 0.9kW. Plot is same for each month.

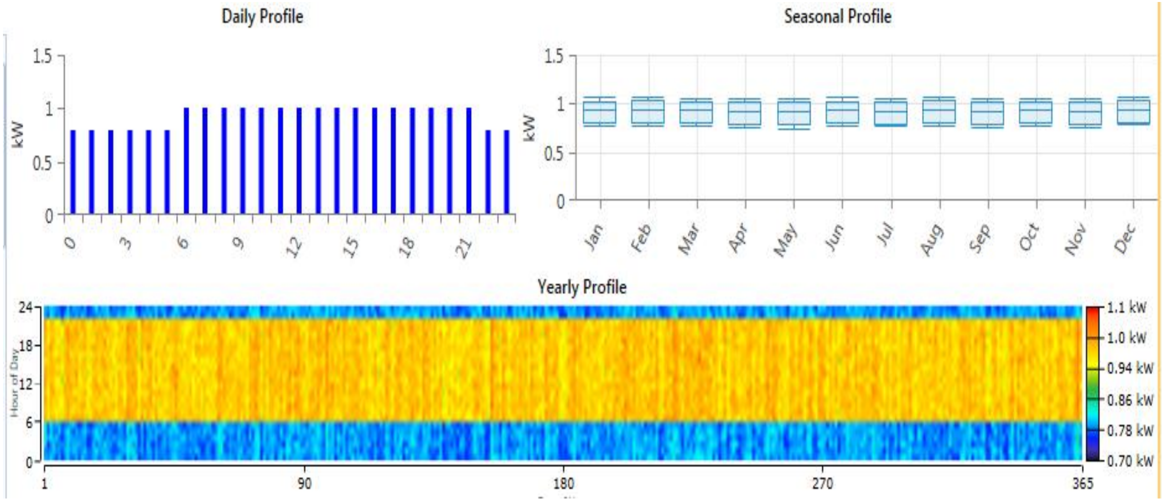


Figure 23:Daily, Seasonal, Yearly Telecom load profile

For daily profile the power required in telecommunication is low for 1:00am to 6:00am and 11:00pm to 12:00pm. Seasonal profile is almost same for every month of a year. Also yearly profile, power of BTS is high when telecommunication traffic is high.

Monthly solar insolation, wind speed and temperature data for the location are taken and assessed with NASA ASDC and SWERA Database. HOMER synthesize these monthly average profiles into hourly data. Scaled annual average daily solar radiation and wind speed is found to be 5.61 kWh/m^2/day and 5.77m/s respectively.

Weather/ Month	Solar Insolation (kW/m^2/day)	Wind Velocity (m/s)	Clearness index
Jan	3.790	6.540	0.624
Feb	4.620	6.750	0.634
Mar	5.550	6.600	0.627
Apr	6.650	6.420	0.648
May	7.450	6.440	0.671
Jun	7.290	5.450	0.640
Jul	6.380	4.110	0.569
Aug	5.790	3.800	0.550
Sep	5.730	4.260	0.616
Oct	5.560	6.010	0.719

Nov	4.610	6.480	0.728
Dec	3.880	6.410	0.683
SAA*	**5.61**	**5.77**	
*SAA: Scaled Annual Average			

Table 5 : Monthly Average Meteorological Data of the Site

Above table defines monthly average data for solar in kW/m^2/day and its clearance index. It also defines the monthly average data of wind in m/s of site that has been selected.

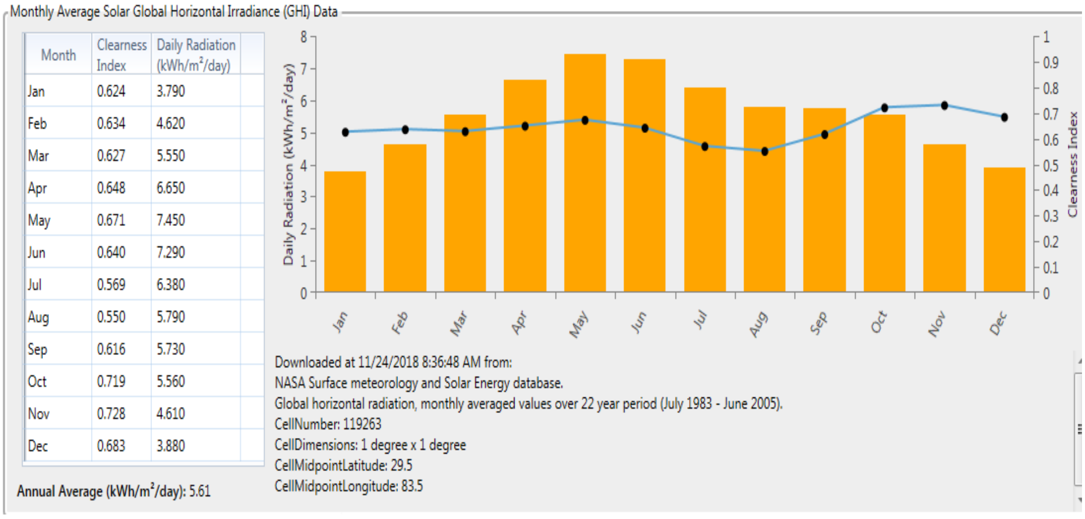


Figure 24: Monthly Average Solar Global Horizontal Irradiance (GHI) data.

The radiation is maximum in April, May, June and reduction in radiation is seen from July to October. Also in January and December decreased radiation is observed.

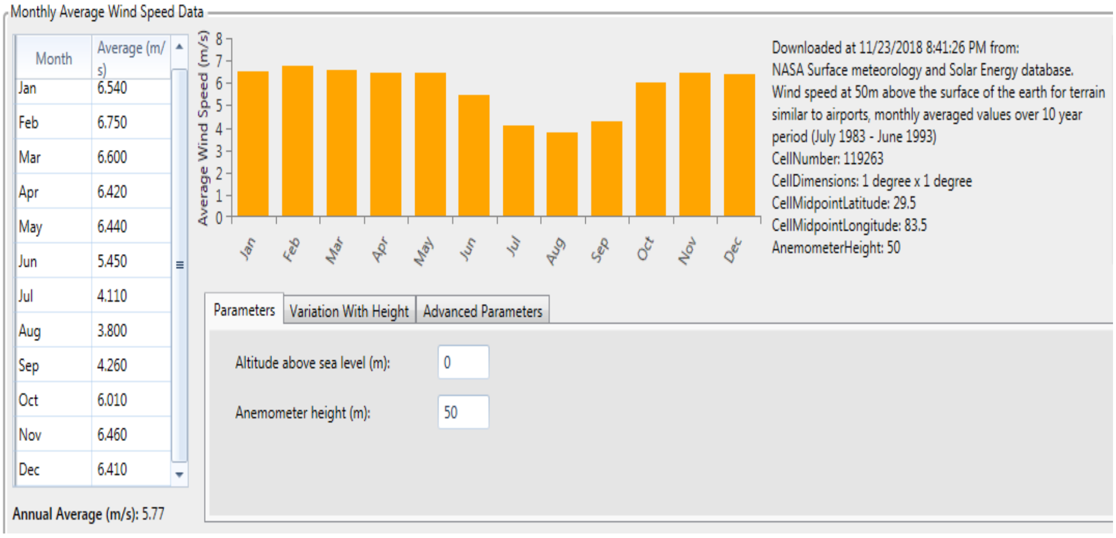
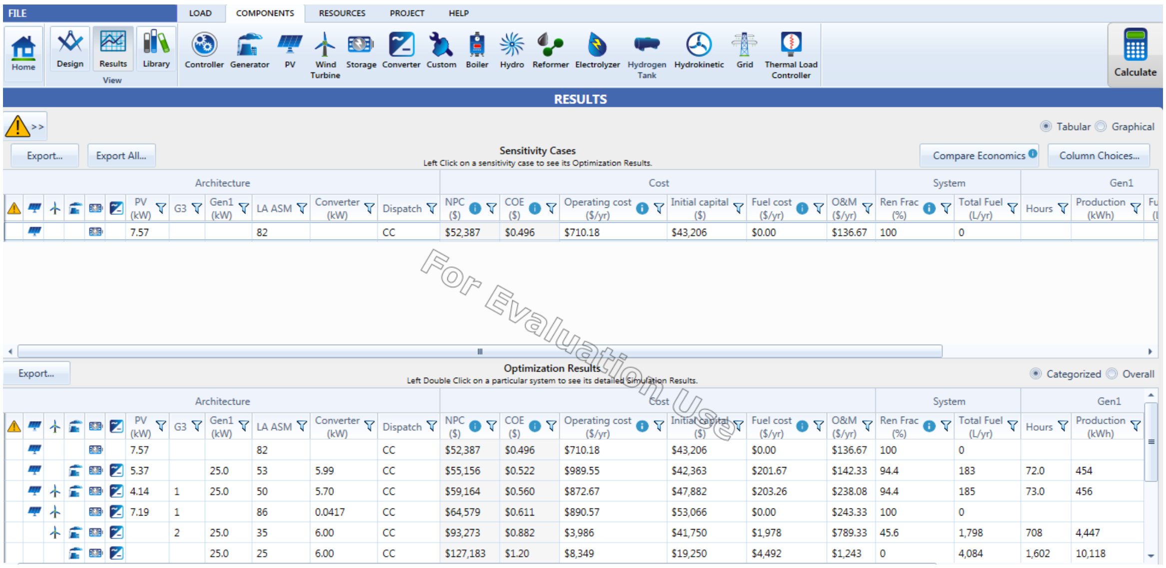


Figure 25: Monthly Average Wind Speed data .

The average speed of wind is found to have minimum value from June to October.

3.2.3 Equipment and their Cost Details

The cost details of system components are presented. But, the cost details of other equipment (Charge Regulator, Charge Controller and Solar-Wind hybrid Controller) are not included. They are supposed to be embedded with associated system estimation and transportation cost and other miscellaneous are not considered for HOMER models developed for this particular study.



PV (kW)	G3	Gen1 (kW)	LA ASM	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Total Fuel (L/yr)	Hours	Production (kWh)
7.57			82		CC	$52,387	$0.496	$710.18	$43,206	$0.00	$136.67	100	0		
5.37		25.0	53	5.99	CC	$55,156	$0.522	$989.55	$42,363	$201.67	$142.33	94.4	183	72.0	454
4.14	1	25.0	50	5.70	CC	$59,164	$0.560	$872.67	$47,882	$203.26	$238.08	94.4	185	73.0	456
7.19	1		86	0.0417	CC	$64,579	$0.611	$890.57	$53,066	$0.00	$243.33	100	0		
	2	25.0	35	6.00	CC	$93,273	$0.882	$3,986	$41,750	$1,978	$789.33	45.6	1,798	708	4,447
		25.0	25	6.00	CC	$127,183	$1.20	$8,349	$19,250	$4,492	$1,243	0	4,084	1,602	10,118

Figure 26: Optimization Result of the Possible Technologies

3.3 Possible Technologies for the system

For finding of possible technologies for the defined site. The model HOMER is set at following value:

(i) Discount rate is set at 8 percentage

(ii) Inflation rate is set at 2.00 percentage

(iii)No annual capacity shortage

(iv)Project lifetime(years) is fixed at 25

3.3.1 Characteristics of various component used in model HOMER

1. Electric Load:

The necessary input data for electric load used in model HOMER are shown below.

i. Random variability:

- Day to day percentage variability is set at 1.5

- Time step percentage variability is set at 1.5

ii. Time step size is of 60 minutes.

iii. Type of load for the system is DC.

iv. Scaled annual average(kWh/day) is 22.40.

2. PV:

The necessary input data for PV used in model HOMER are shown below.

i. Selected PV for the model is generic flat plate PV.

ii. Panel type of PV is of Flat type.

iii. Rated Capacity (KW) of PV is set at 24.

iv. Manufacturer is Generic.

PV capacity(kW)	**Capital ($)**	**Replacement ($)**	**O&M($/year)**
10	30,000	16,000	0.00

v. Lifetime (years) of PV is set at 20.00.

vi. Derating factor (%) is set at 80.

vii. Electrical Bus used is DC.

viii. Ground Reflection is set at 20.

ix. PV component has no Tracking.

x. Model default slope is used which is 29.05 panel slope(degree).

xi. Model default azimuth is used which is panel azimuth (degree w to s).

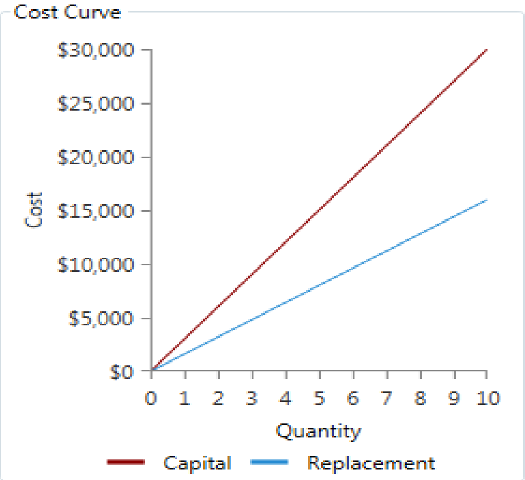


Figure 27: Cost curve of PV

3. Storage**:**

The necessary data for storage used in model HOMER are shown below.

i. Selected storage for this model is generic 1kwh lead acid [ASM].

Quantity	Capital ($)	Replacement ($)	O&M($/years)
48	12,000	12,000	80

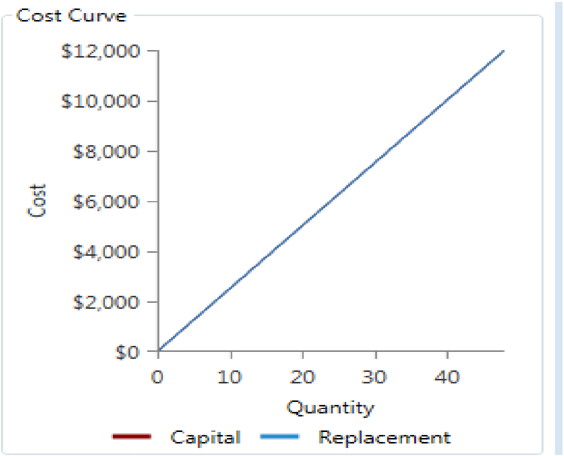


Figure 28: Cost Curve of Storage

ii. Site specific inputs:

- Initial state of charge (%) is set at 100.00.
- Minimum state of charge (%) is set at 40.00.
- Degradation limit (%) is set at 20.00.
- String size1 is used.
- Minimum operating temperature(C) for storage is set at -20.
- Maximum operating temperature(C) for storage is set at 55.
- Maximum charge current(A) of storage is of 167.
- Maximum discharge current(A) of storage is of 500.

4. System converter:

The required input value for system converter used in model HOMER are shown below.

Capacity(kW)	Capital ($)	Replacement ($)	O&M($/year)
6	500.00	500.00	0.0

i. Inverter inputs: Life time (years) is of 15.00

- Efficiency (%) is of 95.00

- Inverter is set parallel with AC generator

ii. Rectifier inputs: Relative Capacity (%) is of 100.00

- Efficiency (%) is of 95.00

5. Wind turbine:

The necessary data of input for wind turbine used in model HOMER are shown below.

i. Selected wind turbine for this model is generic 3kW.

ii. Rated capacity(kW) is set at 3.

iii. Lifetime (years) is of 20.00.

iv. Hub height(m) is of 17.00.

v. Electrical bus used is AC.

Quantity	Capital ($)	Replacement ($)	O&M ($/year)
1	10,000.00	8000.00	100.00

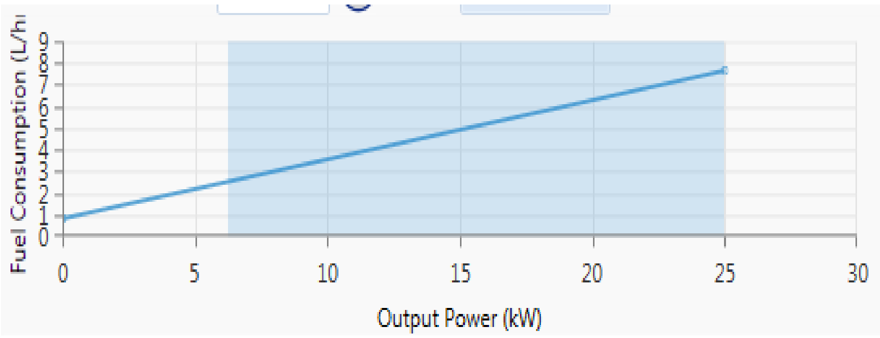


Figure 29: Wind Turbine Fuel Consumption Curve

The curve has linear relationship. The output power rises as fuel consumption increases.

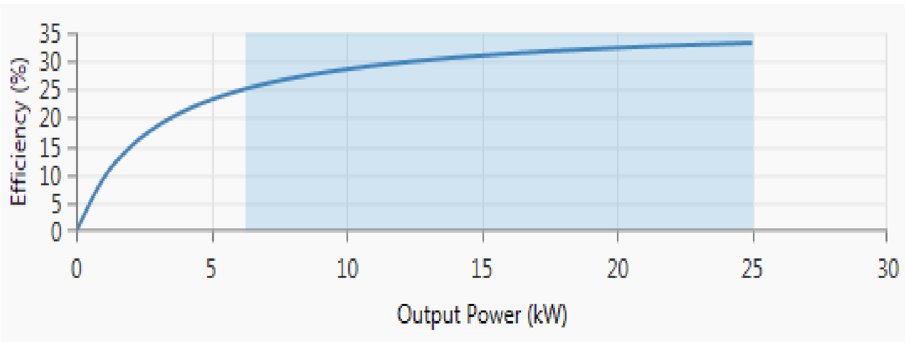


Figure 30: Wind Turbine Efficiency Curve

With increase in Output power, efficiency increase. It reaches maximum value and then gets saturated at particular value.

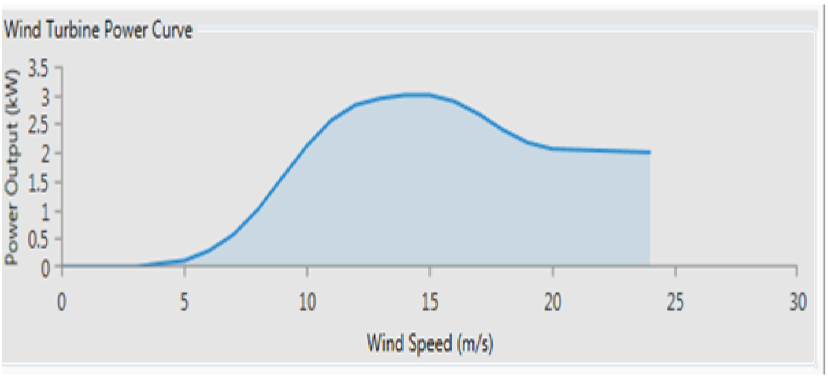


Figure 31: Wind Turbine Power Curve

Increase in wind speed increases output power. Output power reaches maximum value for certain input wind speed data and then gets saturated and becomes independent of windspeed.

Turbine losses is assumed to be 0.

6. Generator:

The necessary input data of generator for model HOMER are shown below.

i. Selected generator for this model is generic 25kW fixed capacity.

ii. Fuel used is Diesel.

iii. Fuel curve intercept is of 0.825 L/hr.

iv. Fuel curve slope is of 0.273L/hr/kW.

v. Emissions of pollutants from selected generator are as follows:

- CO(g/l fuel): 16.34
- Unburned HC(g/l fuel):0.72
- Particulates (g/l fuel): 0.098
- Fuel sulfur to PM(%): 2.2
- Nox(g/l fuel): 15.359

vi. Properties of fuel used for the model are as follows:

- Lower heating value(MJ/Kg): 43.2
- Density(Kg/m^3): 820
- Carbon content(%): 88
- Sulfur content(%): 0.4
- Electrical Bus used is AC

Initial capital ($)	Replacement ($)	O&M ($/operation hour)
12,500.00	12,500.00	0.750

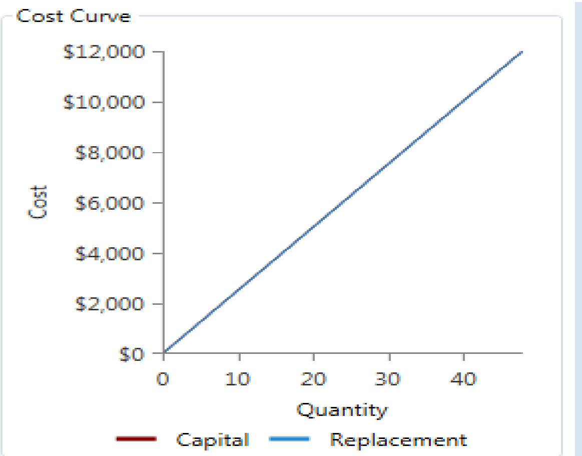


Figure 32: Cost Curve of Generator

vii. Site specific input values of generator used for this model are as follows:

- Minimum load ratio (%):25.00
- Heat recovery ratio (%): 0.00
- Life time(hours): 15,000.00
- Diesel fuel price($/l): 1.10

From above defined assumptions and calculated data of each components the possible technologies defined as model from HOMER model for the selected sites are as follows**:**

3.3.2 Model I: Solar Wind Battery Generator System (SWBG)

Calculated data from HOMER model for SWBG technology are as follows:

1. Net present cost: $59,163.93
2. Levelized cost of energy ($/kWh): $0.560
3. Annualized cost: $4,577
4. Batteries: 50qty
5. Total fuel consumed:185L
6. Avg.fuel per day: 0.506L/day
7. Avg.fuel per hour: 0.0211L/hour

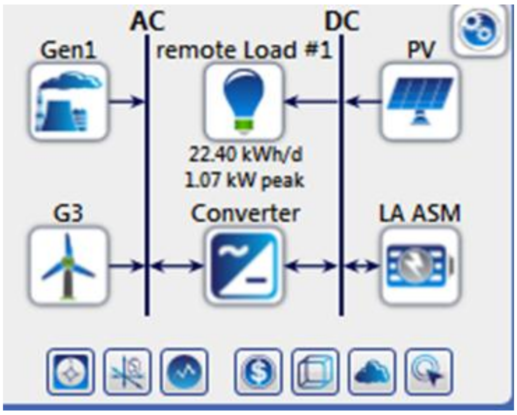


Figure 33 : Model I

System Architecture:

Generator	Generic 25KWfixed capacity Genset
PV	Genset flat plate PV(4.14)KW
Storage	Generic 1KWh lead acid (50)
Wind Turbine	Generic 3KW
System Converter	System Converter(5.70KW)

Table 6 : System Architecture of Model I

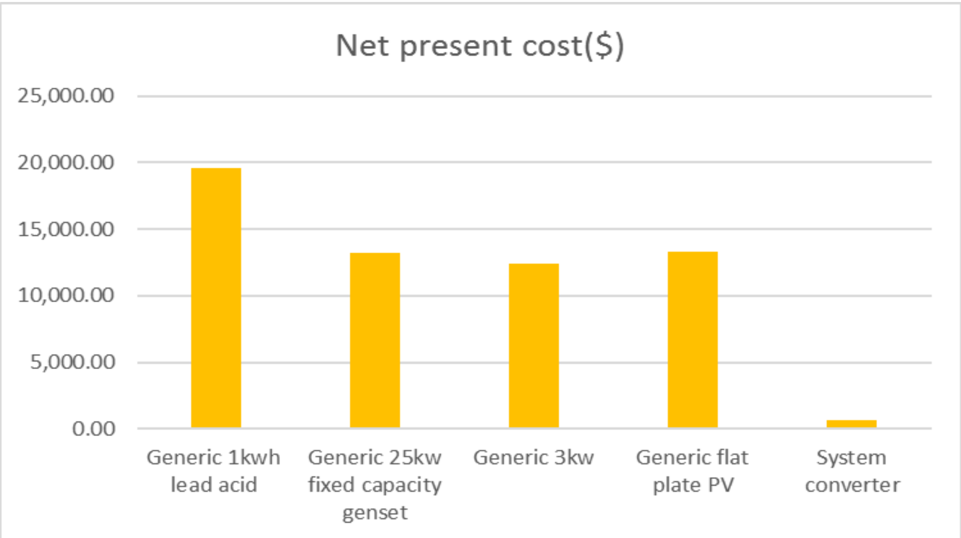


Figure 34: Net Present Cost of Components used in Model I

Production	**kWh/year**	**%**
PV	7,566	65.3
Generic 25KW fixed capacity genset	456	3.94
Generic 3KW	3,556	30.7
Total	11,579	100

Table 7 : Production of Energy from Components used in Model I

The total production of energy is 11,579 kWh/year which is sufficient enough for BTS to operate for a year. Among the total production 65.3% of energy is from PV, 30.7% of energy is from wind system and remaining is from generator.

Consumption	kWh/year	%
AC primary load	0	0
DC primary load	8176	100
Deferrable load	0	0
Total	8176	100

Table 8 : Consumption of Energy of Model I

Here for the Model I BTS consumption of energy is only for DC primary load.

Quantity	kWh/year	%
Excess electricity	2,658	23.0
Unmet electric load	0	0
Capacity storage	0	0
Renewable Fraction		94.4

Table 9 : Electricity profile of Model I

For the Model I excess electricity for BTS is 2658 kWh/year which is stored in storage system. Renewable energy fraction used for the Model I is 94.4% of total energy.

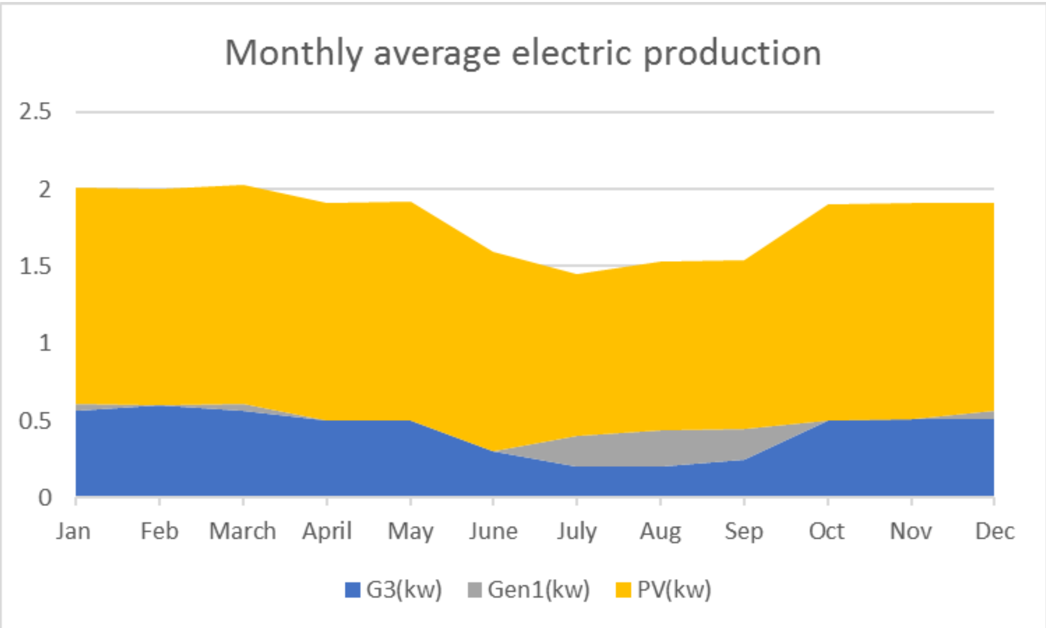


Figure 35: Monthly Average Electric Production of Model I

For Model I electricity production from renewable energy solar and wind together is not enough for month July to October so generator is run to power BTS.

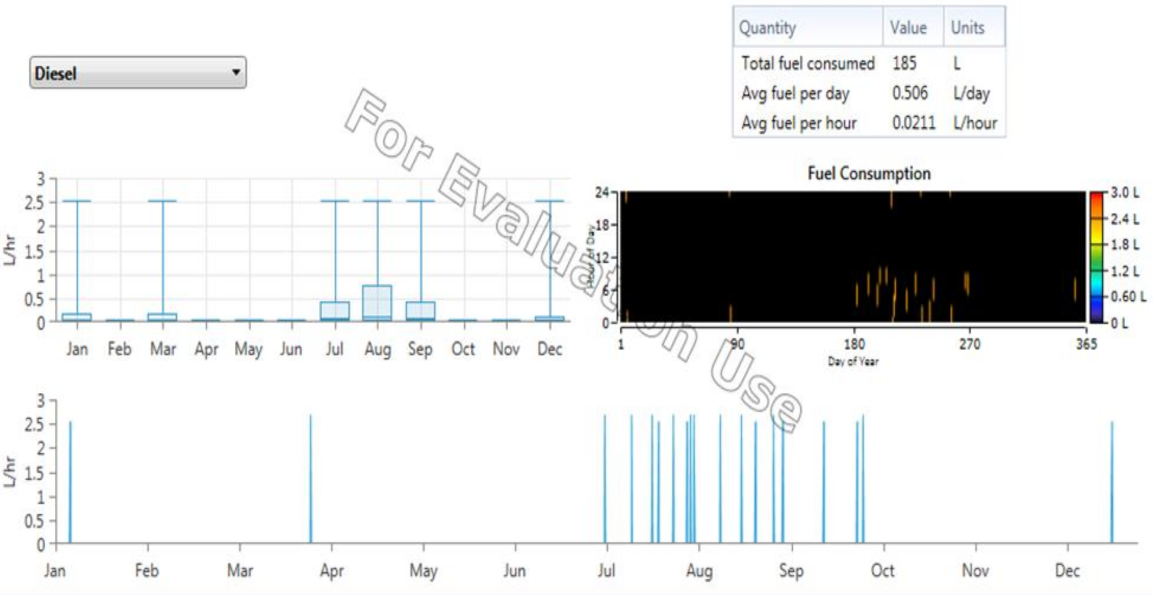


Figure 36: Fuel Consumption of Model I

The fuel consumption is seen much from 180 to 270 day of year. The power generated from solar and wind is not sufficient in month January, March, December and also from July to October so the necessary amount of fuel is used for those months to power BTS .

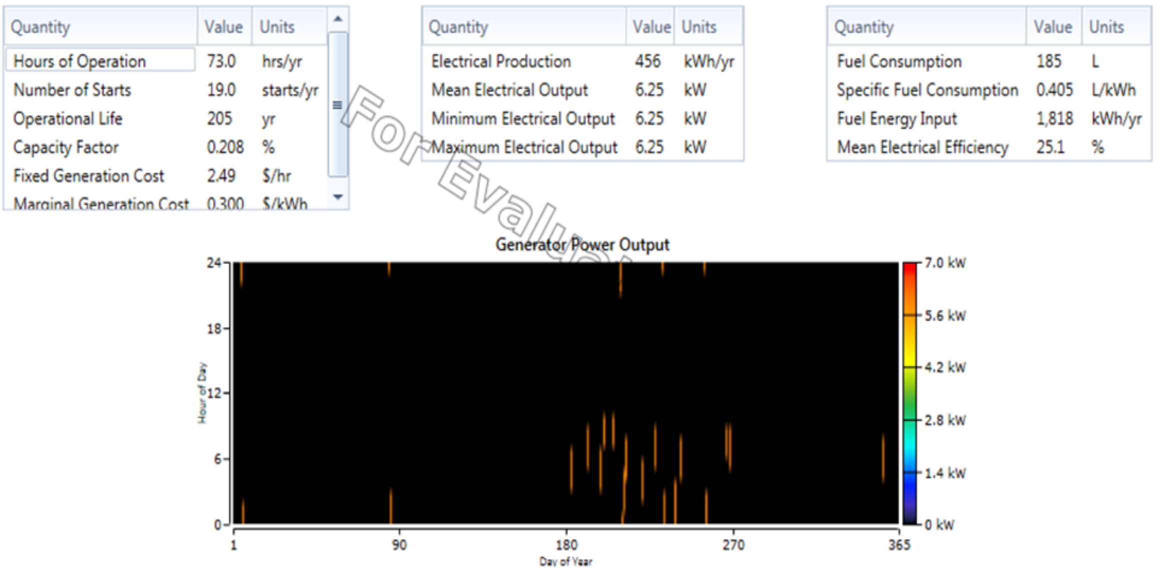


Figure 37: Generator Power Output of Model I

Since the renewable energy cannot generates the sufficient power to operate BTS for 180 to 270 days of year so generator output power is observed much for those days of year.

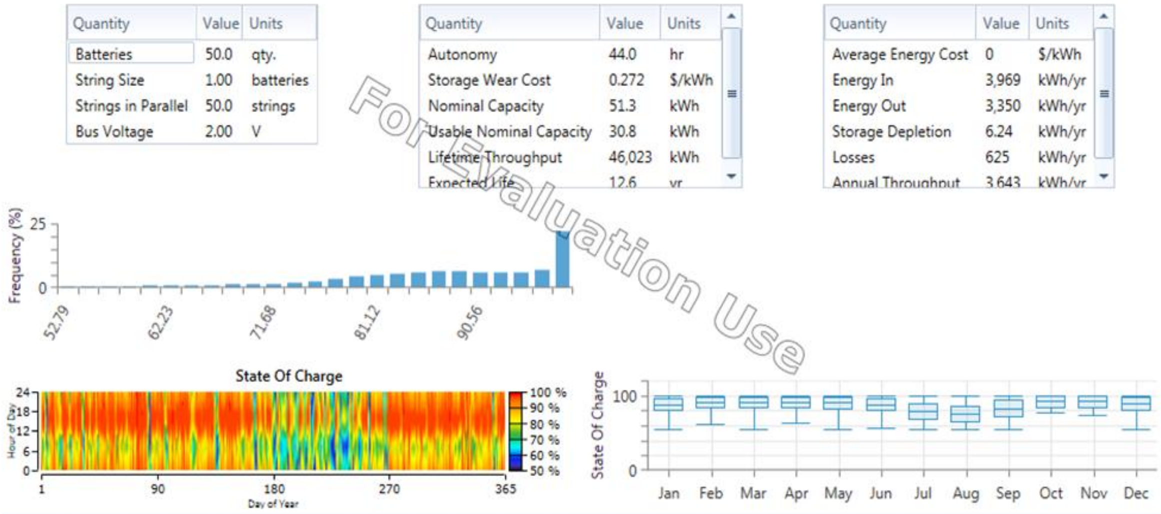


Figure 38: State of Charge of Model I

The state of charge of battery is least for 180 to 270 days of year.

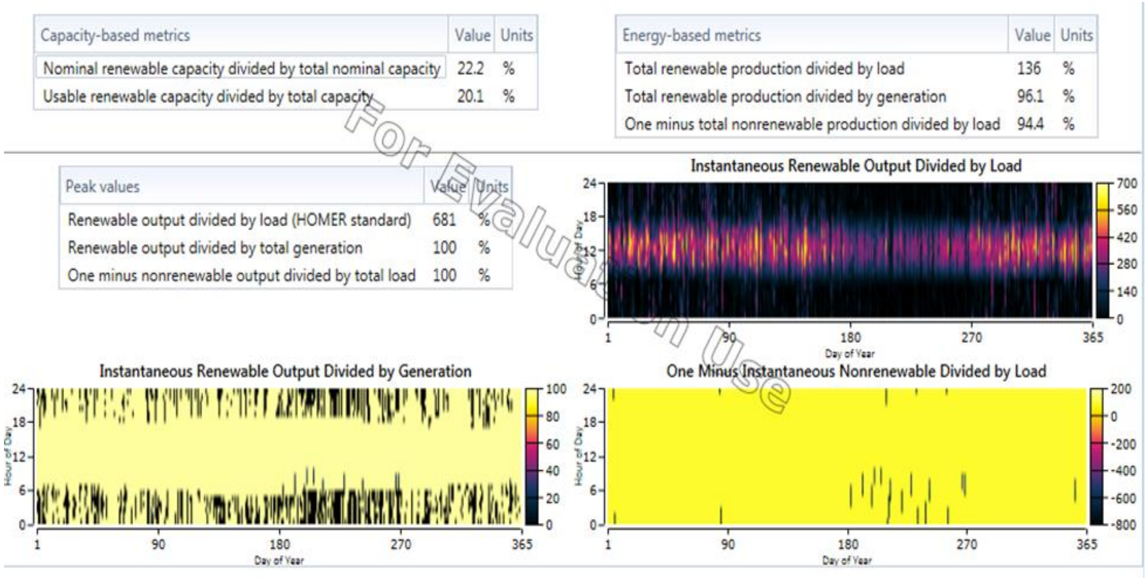


Figure 39: Instantaneous Renewable and Non-renewable Output of Model I

Renewable energy used for this model is solar and wind. The renewable energy output is maximum before sunset and after sunrise because of dependency of solar system. BTS power varies from maximum to minimum traffic load which itself is dependent on hours of a day.

When the power required by BTS is not enough obtained from renewable then generator is run.

Total amount of emissions of pollutants from the Model I are shown in table below.

Pollutant Emissions	Amount (Kg/year)
Carbon Dioxide	484
Carbon monoxide	3.02
Unburned Hydrocarbon	0.133
Particulate Matters	0.0181
Sulfur dioxide	1.18
Nitrogen oxide	2.84

Table 10 : Emission pollutants from Model I

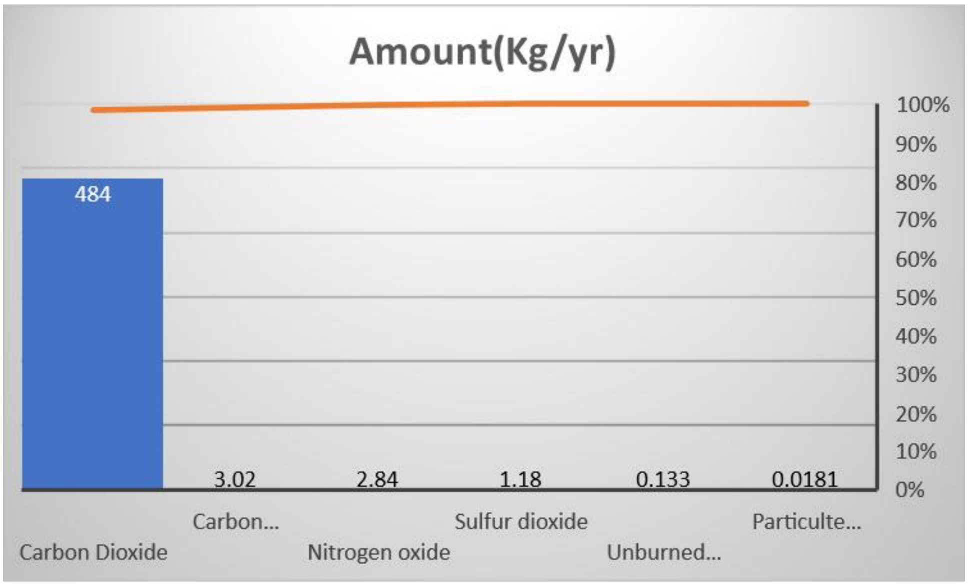


Figure 40: Amount of Pollutants emission of Model I

Among all GHG emissions the amount of CO_2 is maximum. Particulate matters are least emitted in a year for the Model I

3.3.3 Model II: Solar Wind Battery system (SWB)

Calculated data from HOMER model for SWB technology are as follows:

1. Net present cost: $64,578.84
2. Levelized cost of energy ($/kWh): $0.611
3. Annualized cost: $4,995

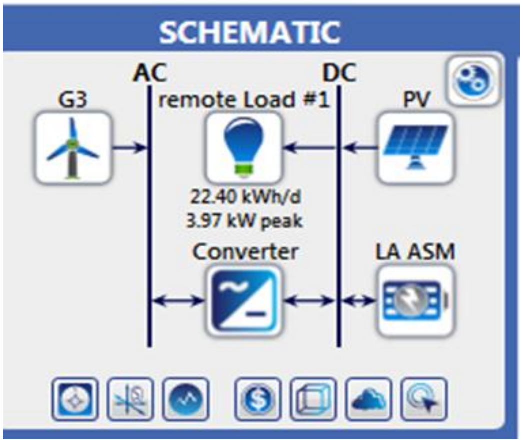


Figure 41 : Model II

System Architecture:

Components	
PV	Generic flat plate PV (7.19KW)
Storage	Generic 1KWH lead acid (86)
Wind turbine	Generic 3KW
System converter	System converter (0.0417 KW)

Table 11: System Architecture of Model II

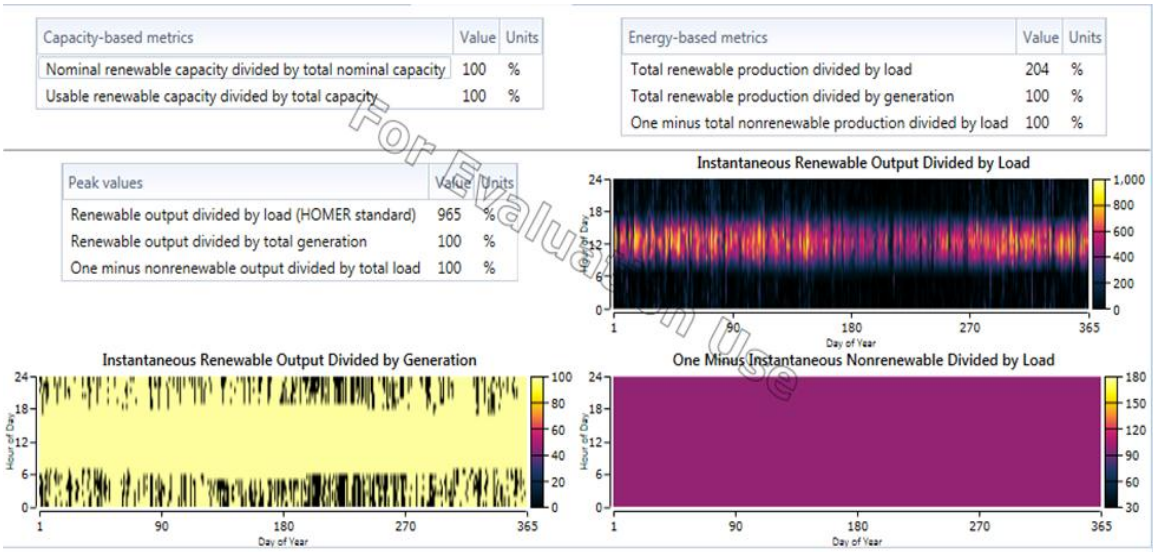


Figure 42: Instantaneous Renewable and Non-renewable Output of Model II

Here for the Model II, it is assumed that the power generated from renewable energy is never insufficient to operate the BTS so generator is not used and fuel consumption is zero.

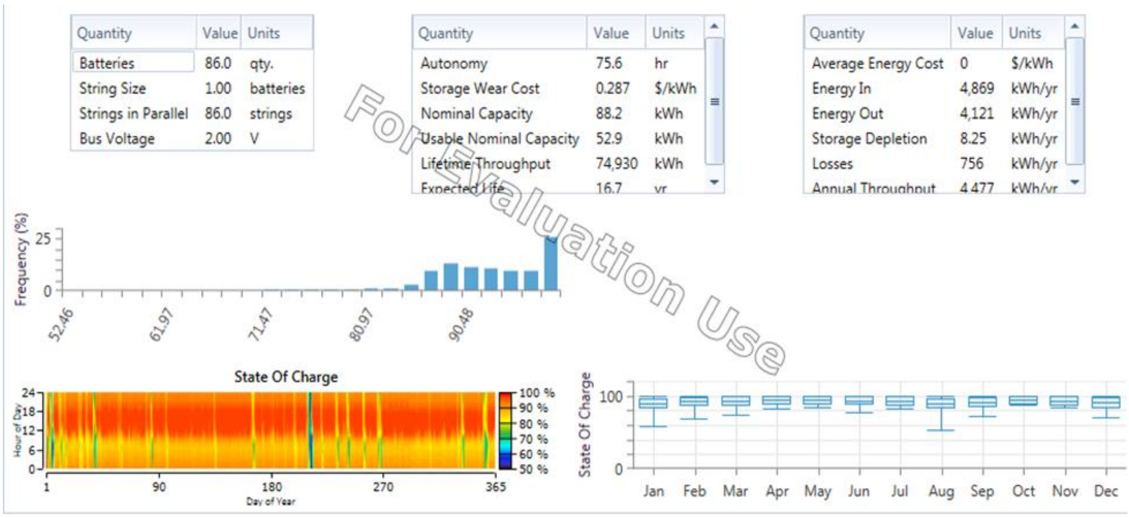


Figure 43: State of Charge of Model II

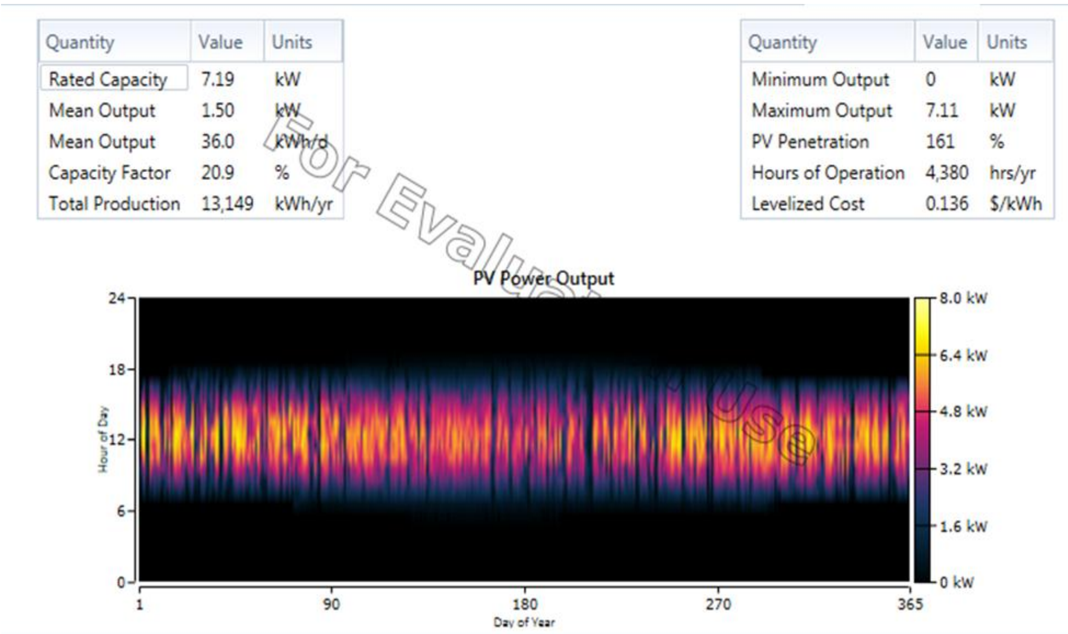


Figure 44: PV Power Output of Model II

The output of PV depends upon solar energy. Power generated by PV is zero before sunrise and after sunset.

Quantity	Value	Units
Total Rated Capacity	3.00	kW
Mean Output	0.406	kW
Capacity Factor	13.5	%
Total Production	3,556	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	3.00	kW
Wind Penetration	43.5	%
Hours of Operation	6,636	hrs/yr
Levelized Cost	0.270	$/kWh

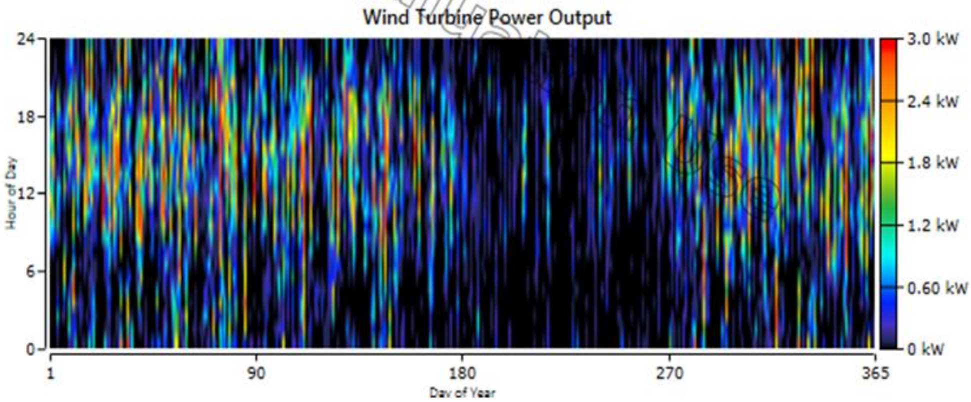


Figure 45: Wind Turbine Power output of Model II

Wind turbine power output varies as per windspeed and The average speed of wind is found to have minimum value from June to October so the power is minimum for that day of year.

3.3.4 Model III: Solar Battery System (SB)

Calculated data from HOMER model for SB technology are as follows:

1. Net present cost: $52,386.81
2. Levelized Cost of energy ($/kWh): $0.496
3. Annualized cost: $4,052

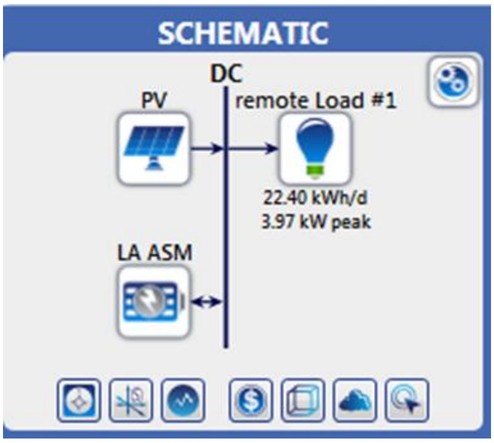


Figure 46 : Model III

System Architecture:

Components	
PV	Generic Flat Plate PV (7.57KW)
Storage	Generic 1KWh Lead acid (82)

Table 12 : System Architecture of Model III

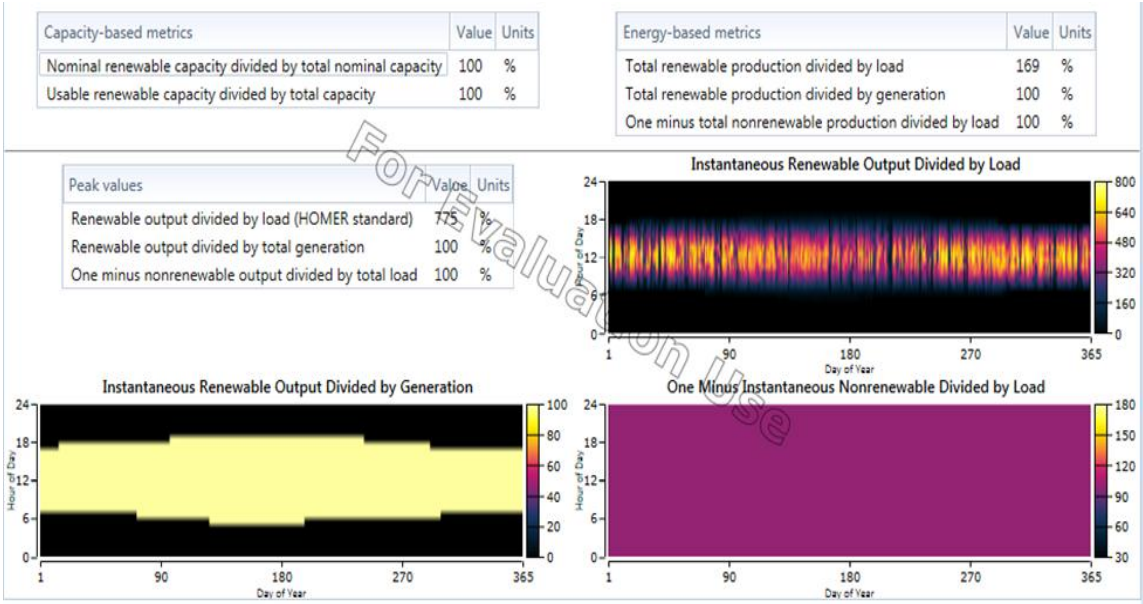
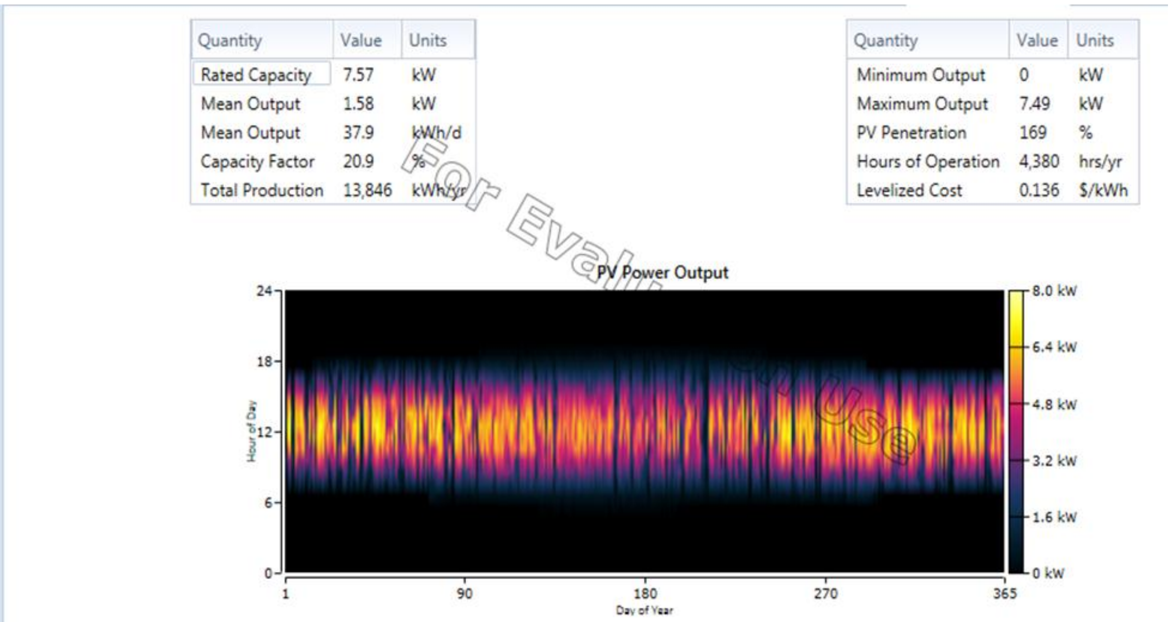


Figure 47: Instantaneous Renewable and Non-renewable Output of Model III

Here for the Model III the power required for BTS is obtained sufficiently from PV system is assumed and excess power is stored in battery at daytime and that stored power is used by BTS at night.

Figure 48: State of Charges of Model III



Quantity	Value	Units
Rated Capacity	7.57	kW
Mean Output	1.58	kW
Mean Output	37.9	kWh/d
Capacity Factor	20.9	%
Total Production	13,846	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	7.49	kW
PV Penetration	169	%
Hours of Operation	4,380	hrs/yr
Levelized Cost	0.136	$/kWh

Figure 49: PV Power Output of Model III

The output of PV depends upon solar energy. Power generated by PV is zero before sunrise and after sunset.

3.3.5 Model IV: Wind Generator Battery System (WGB)

Calculated data from HOMER model for WGB technology are as follows:

1. Net present cost: $93,272.63
2. Levelized cost of energy($/kwh): $0.852
3. Annualized cost: $7215
4. Total fuel consumed :1798L
5. Avg fuel/day: 4.93L/day
6. Avg fuel per hour: 0.205L/hour

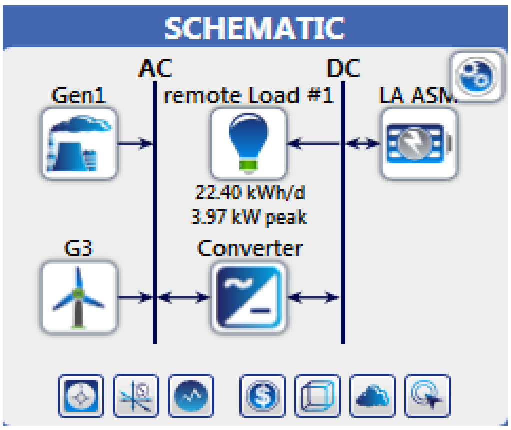


Figure 50 : Model IV

System Architecture:

Components	
Generator	Generic 25KW fixed capacity Genset
Storage	Generic 1Kwh Lead acid (35 strings)
Wind turbine	Generic 3KW (2)
System converter	System converter (6 KW)

Table 13 : System Architecture of Model IV

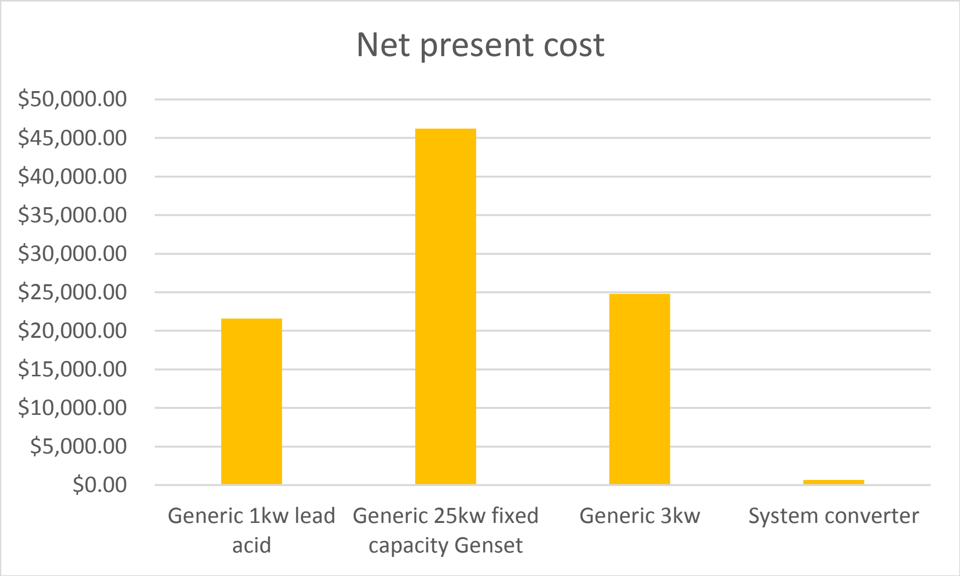


Figure 51: Net Present Cost of components of Model IV

Production	**kWh/year**	**%**
Generic 25Kw fixed capacity Genset	4,447	38.5
Generic 3Kw	7,113	61.5
Total	11,560	100

Table 14 : Energy Production of Model IV

The total production of energy is 11,560 kWh/year which is sufficient enough for BTS to operate for a year. Among the total production 61.5% of energy is from wind system, 38.5% of energy is from generator.

Consumption	**kWh/year**	**%**
AC primary load	0	0
DC primary load	8176	100
Deferrable load	0	0
Total	8176	100

Table 15 :Energy Consumption of Model IV

Here for the Model IV BTS consumption of energy is only for DC primary load

Quantity	**kWh/year**	**%**
Excess electricity	2,046	17.7
Unmet electric load	0	0
Capacity Storage	0	0
Renewable Fraction		45.6

Table 16 : Electricity Profile of Model IV

For the Model IV excess electricity for BTS is 2046 kWh/year which is stored in storage system. Renewable energy fraction used for the Model IV is 45.6% of total energy.

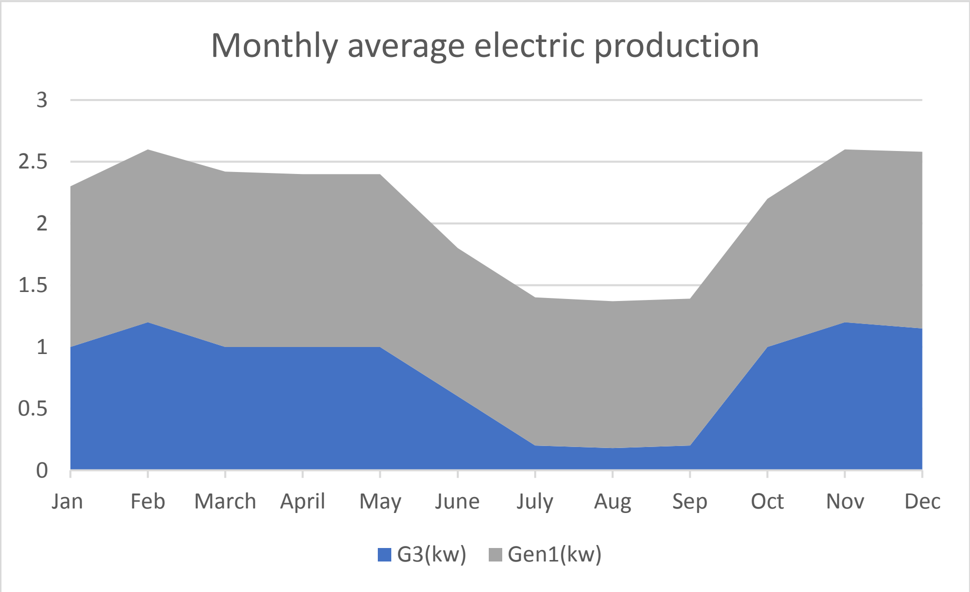


Figure 52: Monthly average electricity production of Model IV

Electricity production from wind system alone for the Model IV is insufficient to run BTS for every month of a year so generator is run to power BTS.

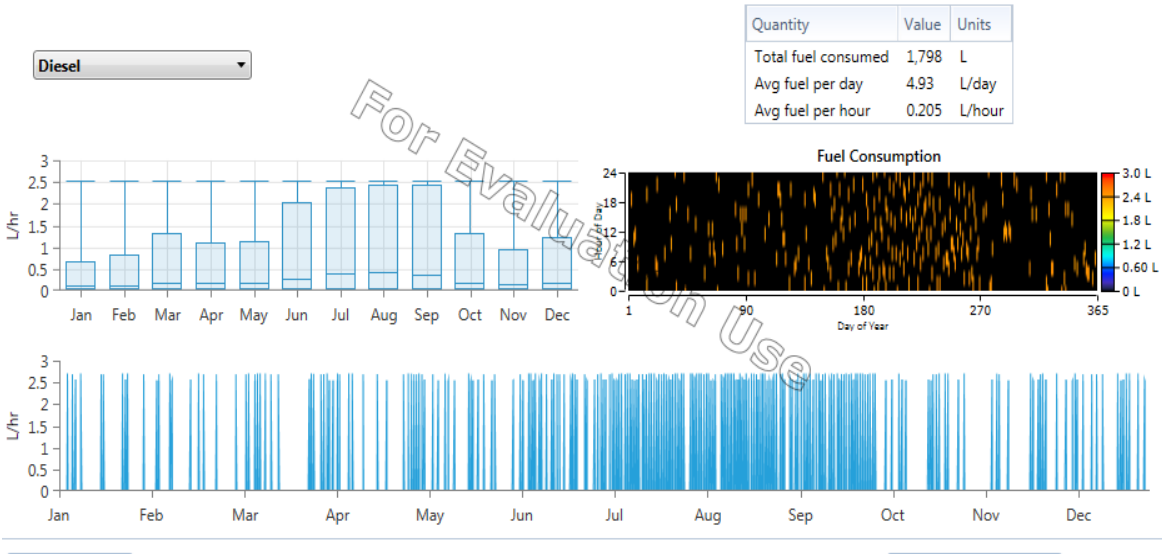


Figure 53: Fuel Consumption of Model IV

Power generated from wind is not sufficient alone to power BTS. Fuel is used when power required is not sufficient and it is almost every month.

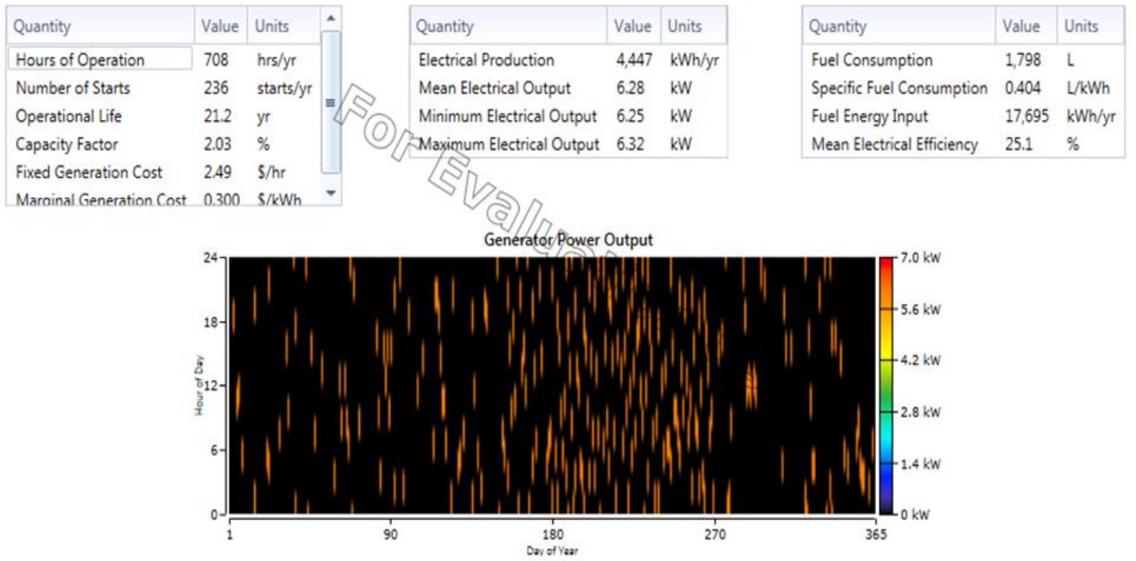


Figure 54:Generator Power Output of Model IV

Generator is operated frequently when power from wind is insufficient to power BTS.

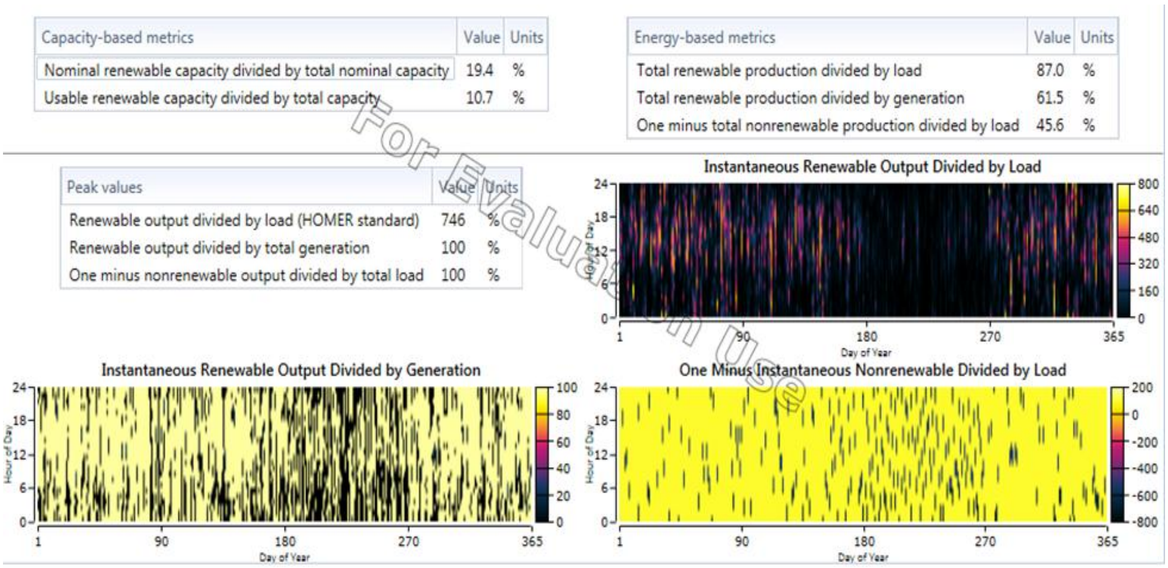


Figure 55: Instantaneous Renewable and Non-renewable Output of Model IV

For 180 to 270 days of year the power generated from wind is minimum so power from generator is much required for those days.

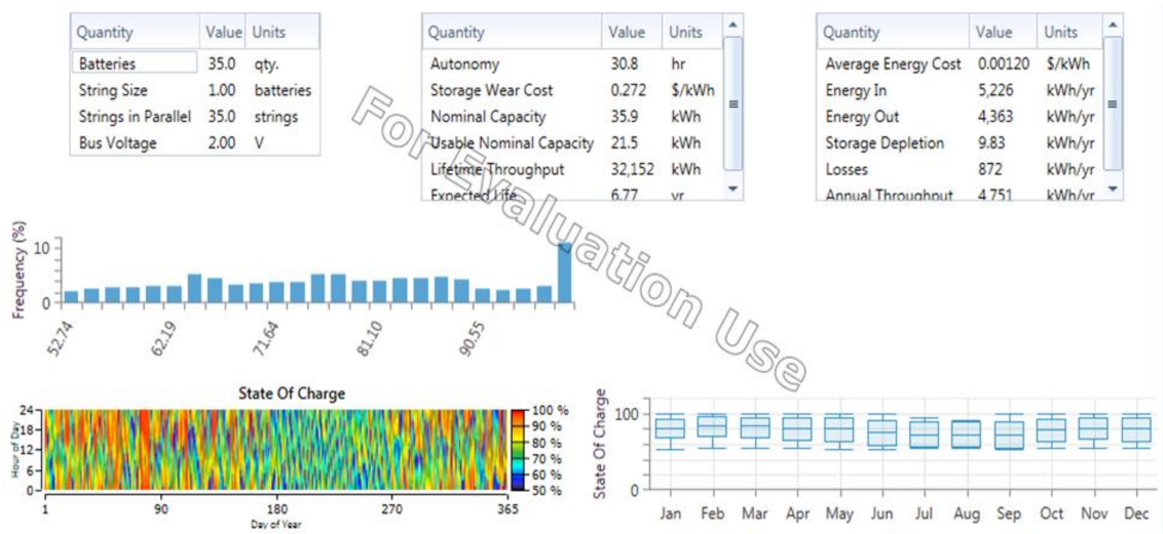


Figure 56: State of Charge of Model IV

State of charge is least for 180 to 270 day of year.

The emissions of pollutants from Model IV are as follows:

Pollutant emissions	**Amount (Kg/year)**
Carbon dioxide	4708
Carbon monoxide	29.4
Unburned hydrocarbon	1.29
Particulate matter	0.179

Sulfur dioxide	11.5
Nitrogen oxide	27.6

Table 17 : Emissions from Model IV

Among all GHG emissions the amount of CO_2 is maximum. Particulate matters are least emitted in a year for the Model IV

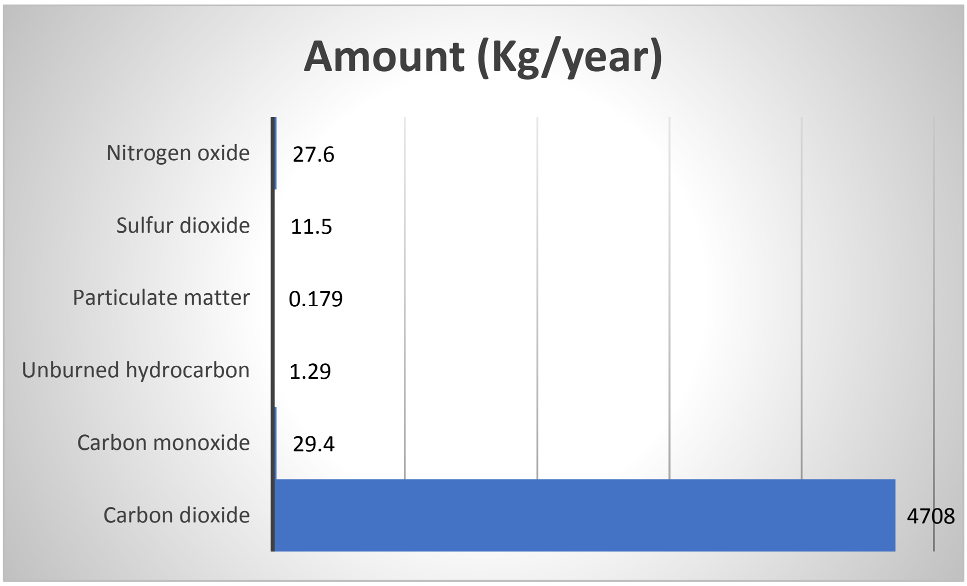


Figure 57: Amount of Pollutant emission of Model IV

3.3.6 Model V: Solar Generator Battery System (SGB)

Calculated data from HOMER model for SGB technology are as follows

1. Net present cost: $55,155.66
2. Levelized cost of energy($/kWh): $0.522
3. Annualized cost: $4,267
4. Total fuel consumed:183L
5. Avg fuel per day:0.502L/day
6. Avg fuel per hour:0.0209L/hour

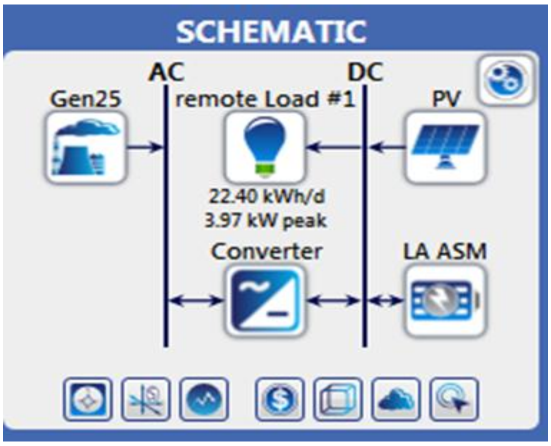


Figure 58 : Model V

System Architecture:

Components	
Generator	Generic 25KW fixed capacity Genset
PV	Generic Flat plate PV (5.37KW)
Storage	Generic 1KWh Lead acid (53)
System converter	System Converter (5.99KW)

Table 18 : System Architecture of Model V

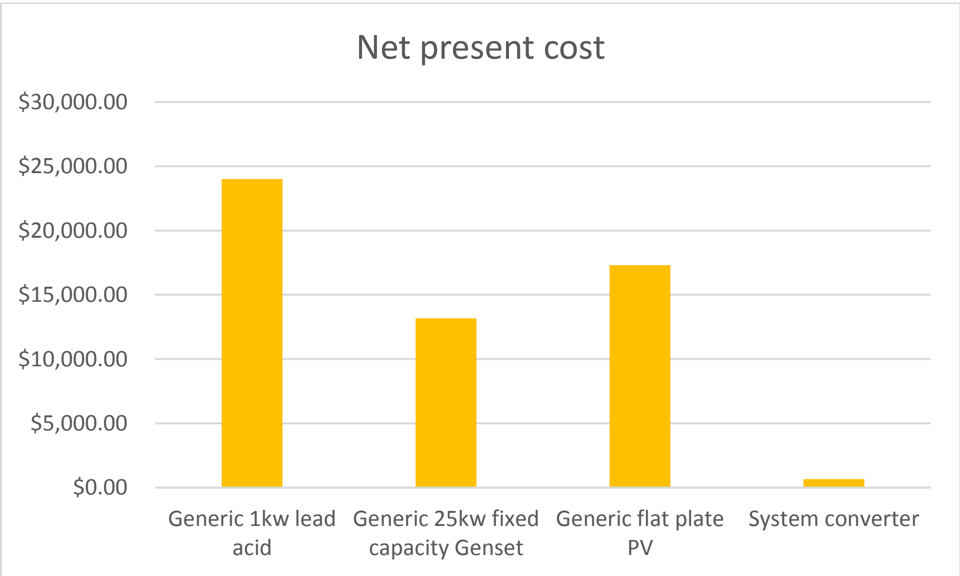


Figure 59: Net Present Cost of Components of Model V

Production	kWh/year	%
Generic flat plate PV	9,827	95.6
Generic 25Kw fixed capacity Genset	454	4.42
Total	10,281	100

Table 19 : Production of Energy of Model V

The total production of energy is 10,281 kWh/year which is sufficient enough for BTS to operate for a year. Among the total production 95.6% of energy is from solar system, rest of energy is from generator.

Consumption	kWh/year	%
AC primary load	0	0
DC primary load	8,176	100
Deferrable load	0	0
Total	8,176	100

Table 20 : Consumption of Energy of Model V

Here for the Model V BTS consumption of energy is only for DC primary load

Quantity	kWh/year	%
Excess electricity	1278	12.4
Unmet Electric load	0	0
Capacity storage	0	0
Renewable fraction		94.4

Table 21 : Electricity Profile of model V

For the Model V excess electricity for BTS is 1278 kWh/year which is stored in storage system. Renewable energy fraction used for the Model V is 94.4% of total energy.

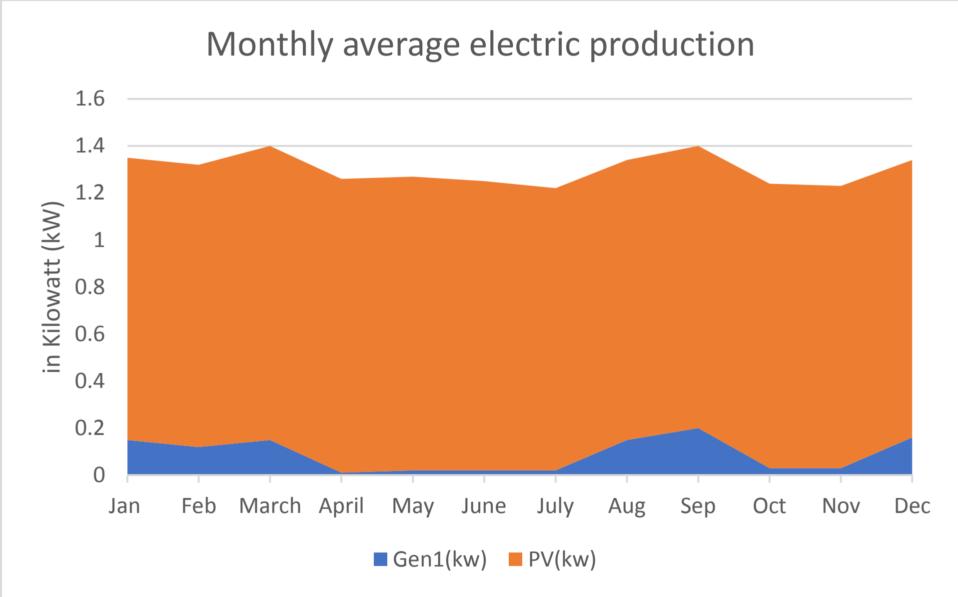


Figure 60: Monthly Average Electric Production of Model V

Only from January to March and July to October some noticeable amount of energy is generated from generator. Almost all energy for BTS is obtained from PV and where there is deficiency the generator is run.

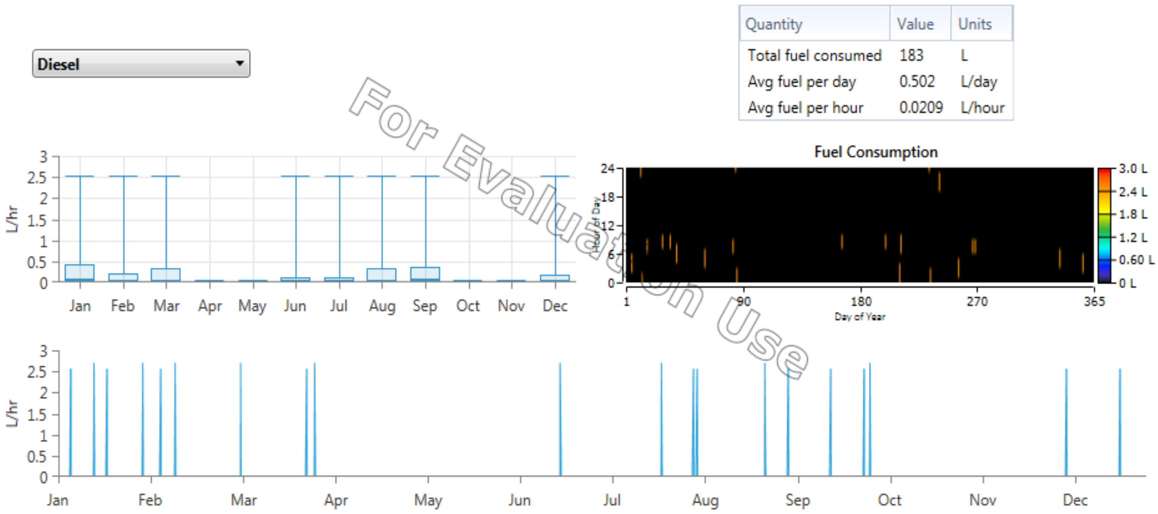


Figure 61: Fuel Consumption of Model V

The power from PV is not sufficient to operate BTS for some of months of a year so diesel is used to power BTS for those day of year.

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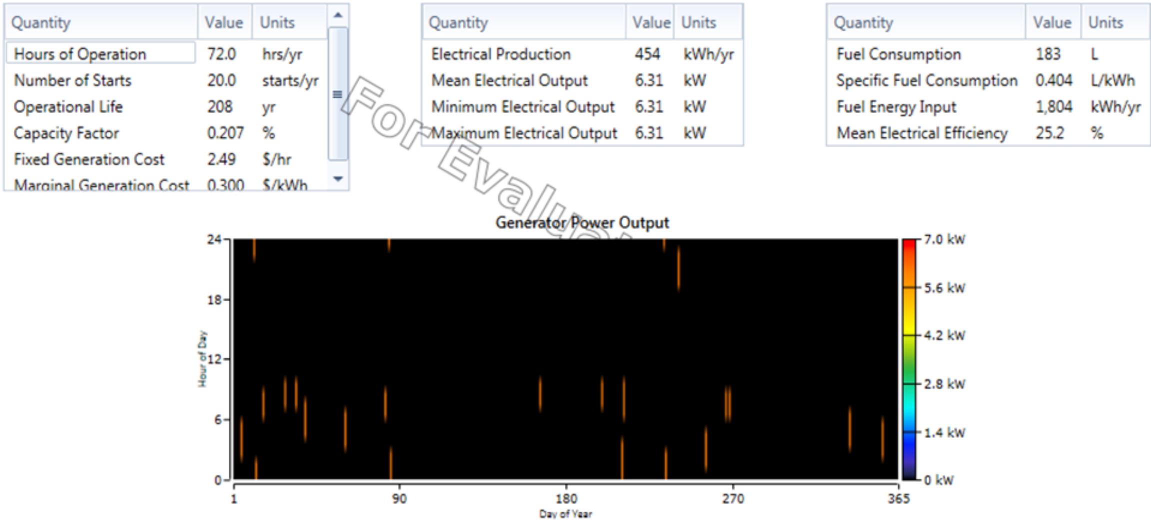


Figure 62: Generator Power Output of Model V

Generator is used for some day of year where power from PV becomes insufficient to operate BTS.

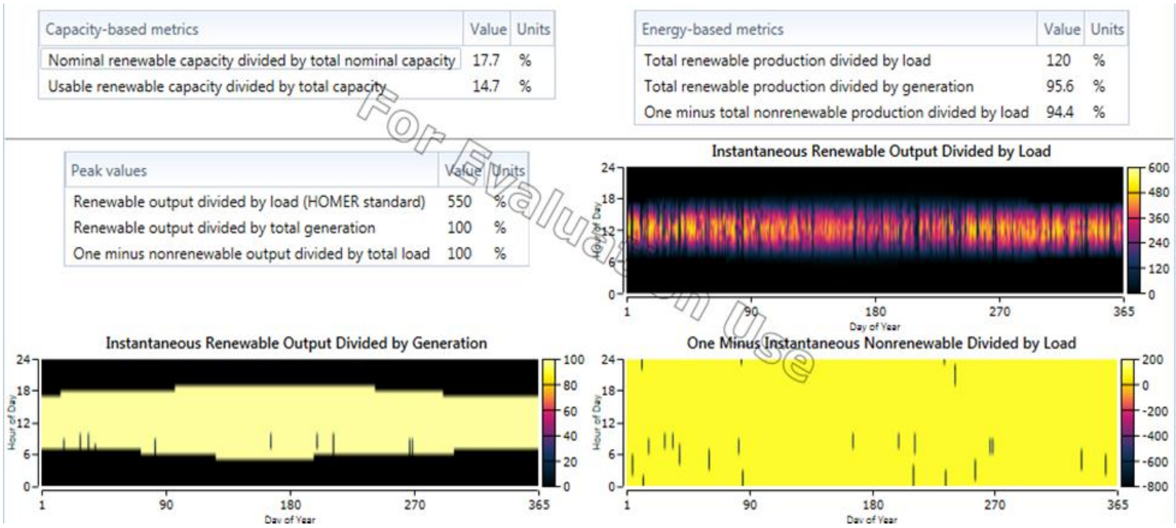


Figure 63: Instantaneous Renewable and Non-renewable Output of Model V

Excess power from PV is stored in battery at daytime and are used at night to operate BTS. Non renewable energy is used for case where power from PV becomes insufficient.

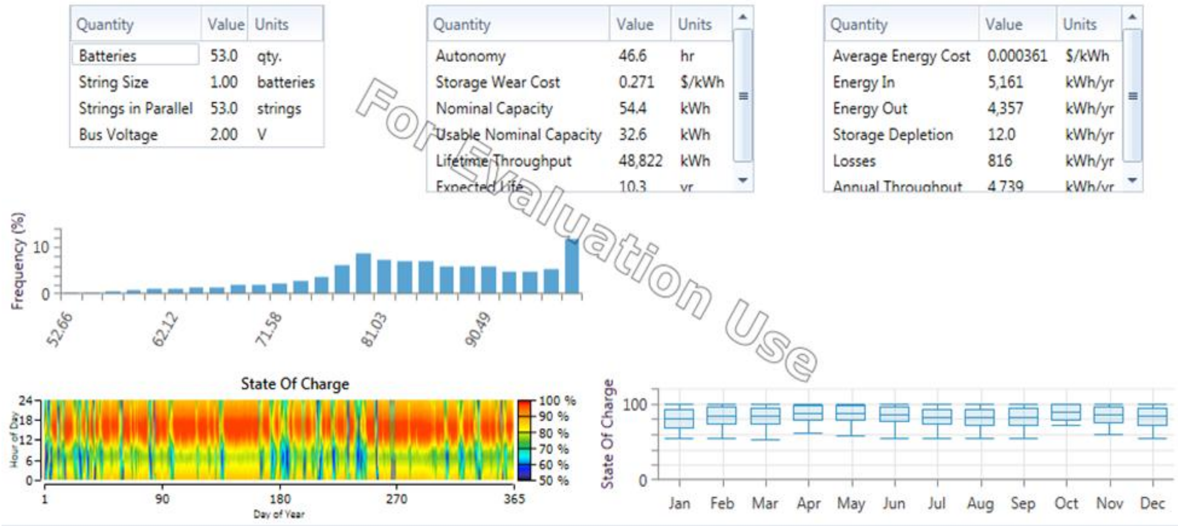


Figure 64: State of Charge of Model V

The emissions of pollutants from Model V

Pollutants	**Amount (Kg/year)**
Carbon dioxide	480
Carbon monoxide	3.00
Unburned hydrocarbon	0.132
Particulate matter	0.0186
Sulfur dioxide	1.18
Nitrogen oxides	2.82

Table 22 : Amount of Pollutant emission of Model V

Among all GHG emissions the amount of CO_2 is maximum. Particulate matters are least emitted in a year for the Model V

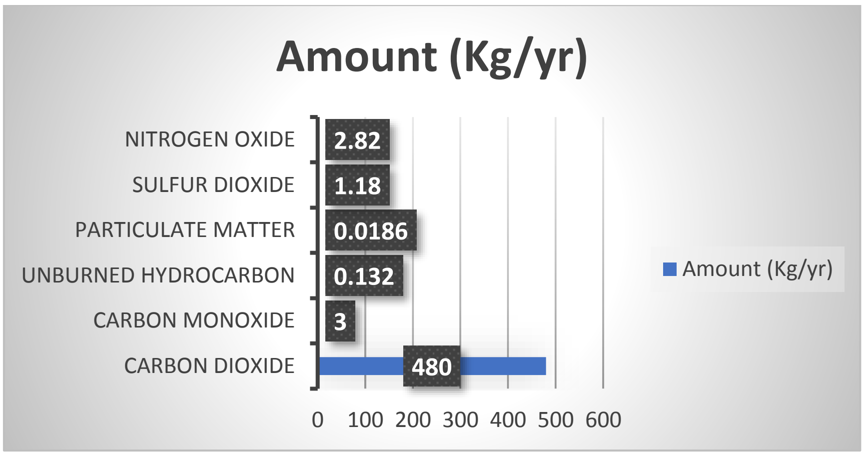


Figure 65: Amount of Pollutant emission of Model V

3.3.7 Model VI: Wind Battery System (WB)

Calculated data from HOMER model for WB technology are as follows:

1. Total present cost: $312,891.60
2. Levelized cost of energy: $2.96
3. Annualized costs: $24,204

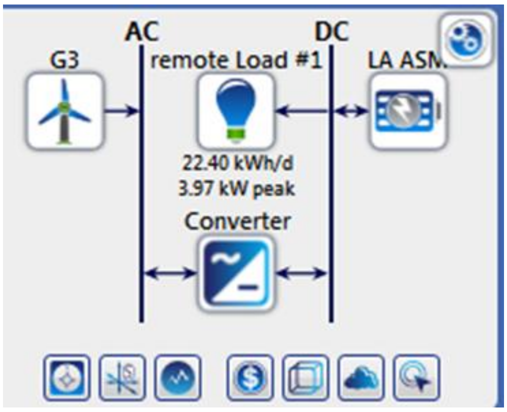


Figure 66 : Model VI

System Architecture:

Storage	1KW (300)
Wind turbine	3KW (17)
System converter	7.22KW

Table 23 : System Architecture of Model VI

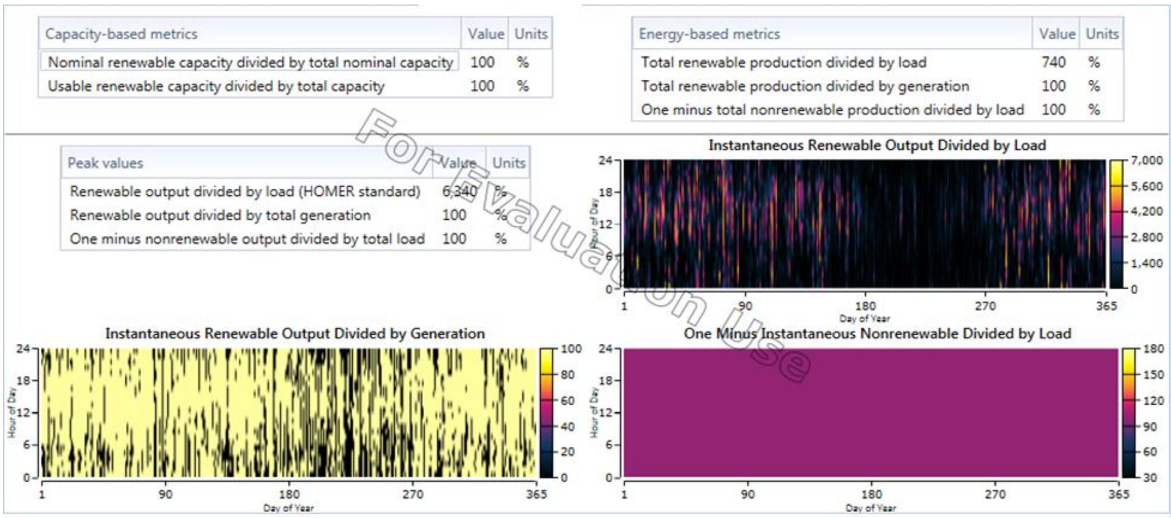
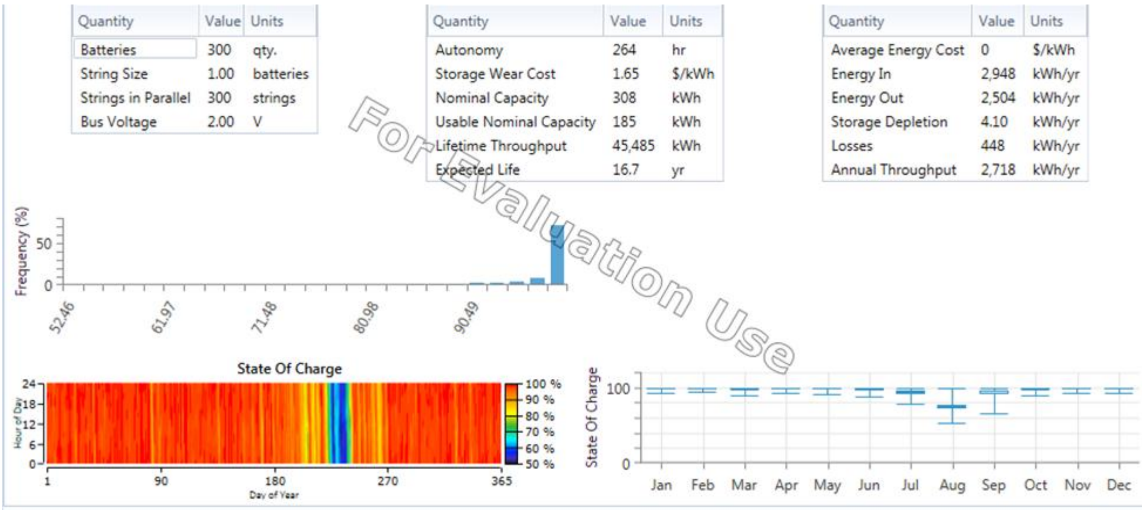


Figure 67: Instantaneous Renewable and Non-renewable Output of Model VI

The output from wind system is least from 180 to 270 days of year. Power from wind system varies as per hour of day depending upon windspeed. No non renewable energy is used for the Model VI.

ISSN: 2278-0181



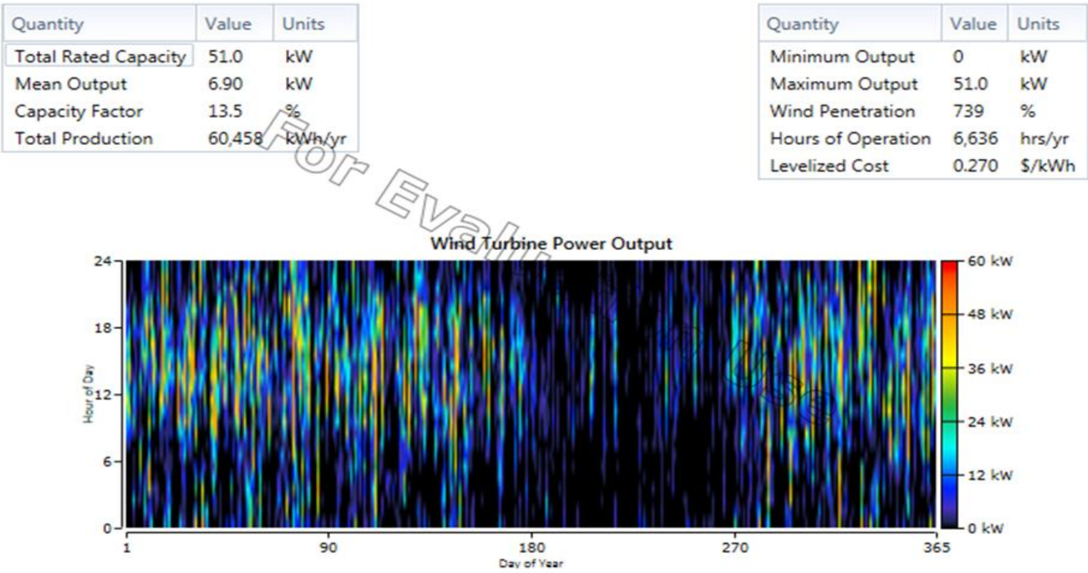
Quantity	Value	Units
Batteries	300	qty.
String Size	1.00	batteries
Strings in Parallel	300	strings
Bus Voltage	2.00	V

Quantity	Value	Units
Autonomy	264	hr
Storage Wear Cost	1.65	$/kWh
Nominal Capacity	308	kWh
Usable Nominal Capacity	185	kWh
Lifetime Throughput	45,485	kWh
Expected Life	16.7	yr

Quantity	Value	Units
Average Energy Cost	0	$/kWh
Energy In	2,948	kWh/yr
Energy Out	2,504	kWh/yr
Storage Depletion	4.10	kWh/yr
Losses	448	kWh/yr
Annual Throughput	2,718	kWh/yr

Figure 68: State of Charge of Model VI

State of charge of battery is least between 180 to 270 days of year.



Quantity	Value	Units
Total Rated Capacity	51.0	kW
Mean Output	6.90	kW
Capacity Factor	13.5	%
Total Production	60,458	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	51.0	kW
Wind Penetration	739	%
Hours of Operation	6,636	hrs/yr
Levelized Cost	0.270	$/kWh

Figure 69: Wind Turbine Power Output of Model VI

Power from wind turbine has deviation depending upon wind speed.

3.3.8 Model VII: Generator Battery System (GB)

Calculated data from HOMER model for GB technology are as follows:

1. Total present cost: $127,182.60
2. Levelized cost of energy($/kWh): $1.20
3. Annualized cost: $9838
4. Total fuel consumed:4,084L
5. Avg fuel per day:11.2L/day
6. Avg. fuel per hour:0.466L/hour

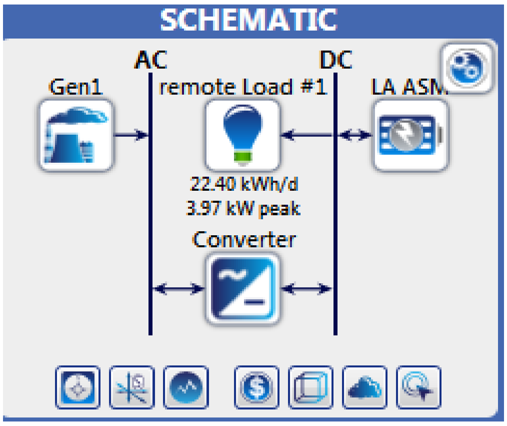


Figure 70 : Model VII

System Architecture:

Generator	25KW
Storage	1 KW (25)
System converter	6KW

Table 24 : System Architecture of Model VII

The emissions of pollutants from the Model VII are as follows

Pollutant emissions	**Amount(Kg/year)**
Carbon dioxide	10691
Carbon monoxide	66.7
Unburned hydrocarbon	2.94
Particulate matter	0.400
Sulfur dioxide	26.2
Nitrogen oxide	62.7

Table 25 : Emissions of Pollutants of Model VII

Among all GHG emissions the amount of CO_2 is maximum. Particulate matters are least emitted in a year for the Model VII

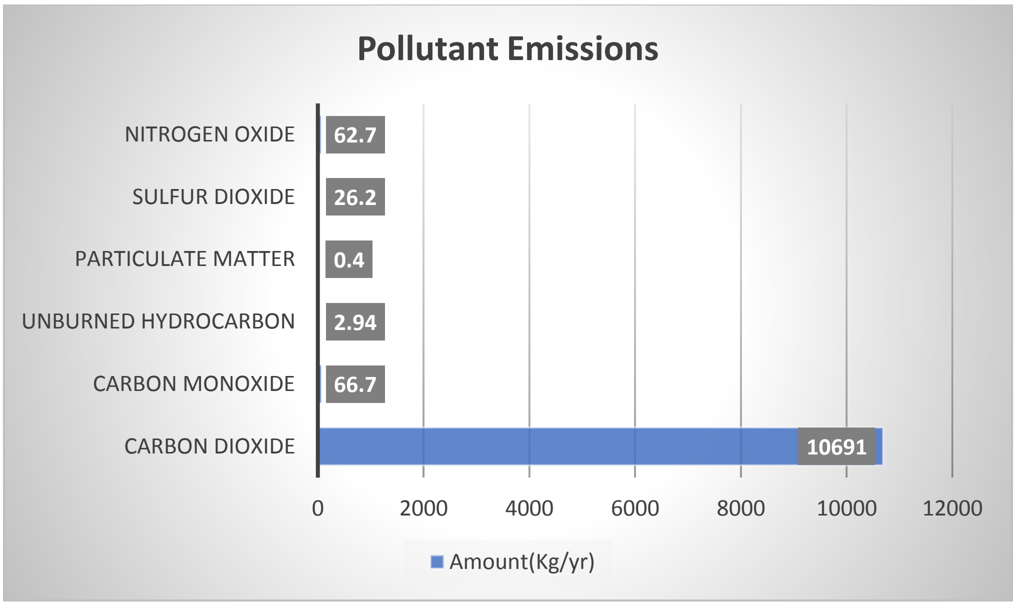


Figure 71: Pollutant Emission of Model VII

3.3.9 Model VIII: Generator System (DG)

Calculated data from HOMER model for DG technology are as follows:

1. Total present cost: $502,363.30
2. Levelized cost of energy($/kWh): $4.75
3. Annualized cost: $38,860
4. Total fuel consumed:22,174L
5. Avg fuel/day:60.8L/day
6. Avg fuel/hr:2.53L/hr

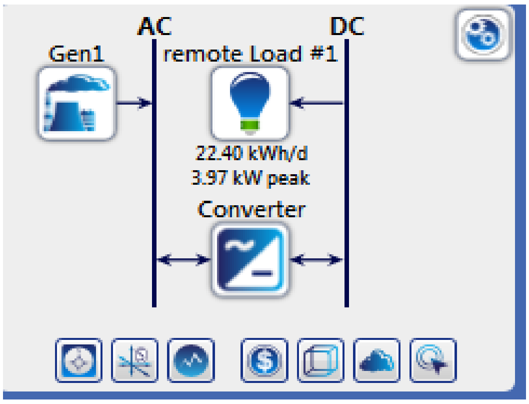


Figure 72 : Model VIII

System Architecture:

Generator	25KW
System converter	1.14KW

Table 26 : System Architecture of Model VIII

The emissions of pollutants from Model VIII are as follows:

Pollutant emissions	**Amount (Kg/year)**
Carbon dioxide	58,048
Carbon monoxide	362
Unburned hydrocarbon	16.0
Particulate matter	2.17
Sulfur dioxide	142
Nitrogen oxide	341

Table 27 : Emissions of Pollutants of Model VIII

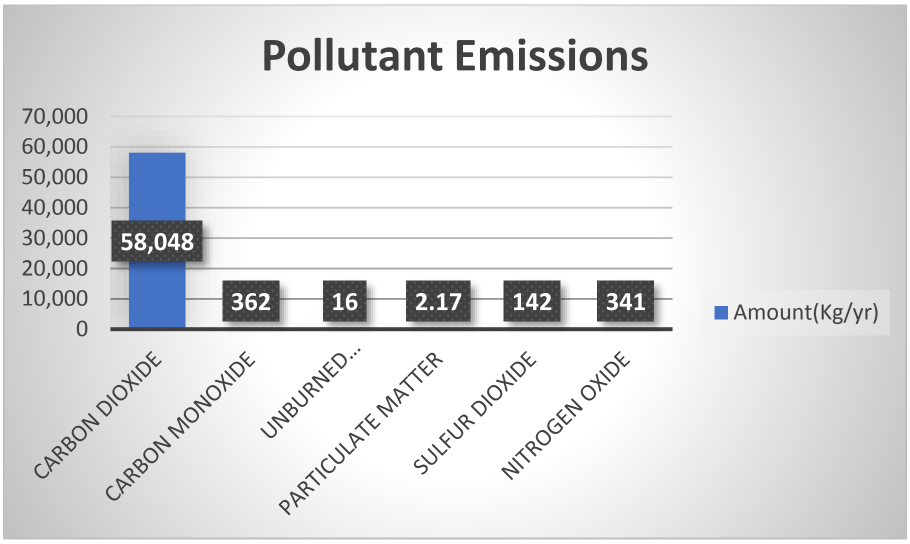
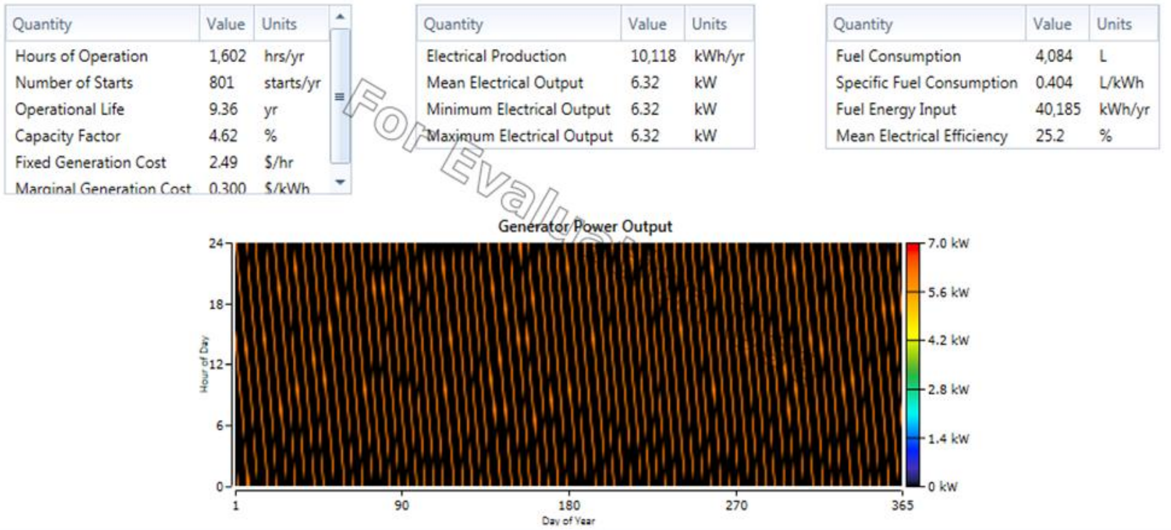


Figure 73: Pollutant emission of Model VIII

Figure 74: Fuel Consumption of Model VIII

Fuel consumption is maximum for this model. Power required for BTS is obtained from generator.



Quantity	Value	Units
Hours of Operation	1,602	hrs/yr
Number of Starts	801	starts/yr
Operational Life	9.36	yr
Capacity Factor	4.62	%
Fixed Generation Cost	2.49	$/hr
Marginal Generation Cost	0.300	$/kWh

Quantity	Value	Units
Electrical Production	10,118	kWh/yr
Mean Electrical Output	6.32	kW
Minimum Electrical Output	6.32	kW
Maximum Electrical Output	6.32	kW

Quantity	Value	Units
Fuel Consumption	4,084	L
Specific Fuel Consumption	0.404	L/kWh
Fuel Energy Input	40,185	kWh/yr
Mean Electrical Efficiency	25.2	%

Figure 75: Generator Power Output of Model VIII

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 HOMER Output Analysis

Possible renewable energy technologies have been modeled through HOMER so as to assess the most feasible RET solution via optimized results. The study basically deals with eight models. The Output Analysis of defined Models are as follows.

4.1.1 HOMER Output Analysis for Model I (SWBG)

This model of telecom load 22.40 kWh/day and diesel price $1.10/liter conveys a large NPC $59,163.93. It reveals that a telecom tower powered by SWBG consume 185 liters in a year. Average fuel per day is 0.506 liters and average fuel per hour consumption is 0.0211 liters. Among the total production 65.3% of energy is from PV, 30.7% of energy is from wind system and remaining is from generator.

Renewable energy fraction used for the Model I is 94.4% of total energy. CO_2 emission is found to be 484 kg followed by 3.02 kg of CO emission per year per telecom tower.

The total electrical energy production from the Model I is found to be 11,579 kWh/year with DC primary load consumption of 8176 kWh resulting an excess of electricity 2658 kWh/year with no capacity shortage.

4.1.2 HOMER Output Analysis for Model II(SWB)

This model of telecom load 22.40 kWh/day conveys a NPC $64,578.84. Since the Model II uses renewable energy. Though assumption for the Model II is that the energy to power BTS is enough obtained from renewable energy. Weather is unpredictable so backup system is required for unpredictable situation. This model seems ideal for selected site.

4.1.3 HOMER Output Analysis for Model III (SB)

This model of telecom load 22.40 kWh/day conveys a NPC $52,386.81. Since the Model III uses only solar system. Though assumption is that the energy to power BTS is enough obtained from solar which seems ideal for the selected site.

4.1.4 HOMER Output Analysis for Model IV (WGB)

This model of telecom load 22.40 kWh/day and diesel price $1.10/liter conveys a large

NPC $93,272.63. It reveals that a telecom tower powered by WGB consume 1798 liters in a year. Average fuel per day is 4.93 liters and average fuel per hour consumption is 0.205 liters. Among the total production, 61.5% of energy is from wind system and 38.5% of energy is from generator.

Renewable energy fraction used for the Model IV is 45.6% of total energy. CO_2 emission is found to be 4708 kg followed by 29.4 kg of CO emission per year per telecom tower.

The total electrical energy production from the Model IV is found to be 11,560 kWh/year with DC primary load consumption of 8176 kWh resulting an excess of electricity 2046 kWh/year with no capacity shortage

4.1.5 HOMER Output Analysis for Model V(SGB)

This model of telecom load 22.40 kWh/day and diesel price $1.10/liter conveys a large NPC $55,155.66. It reveals that a telecom tower powered by SGB consume 183 liters in a year. Average fuel per day is 0.502 liters and average fuel per hour consumption is 0.0209 liters. Among the total production 95.6% of energy is from PV system and 4.42% of energy is from generator.

Renewable energy fraction used for the Model V is 94.4% of total energy. CO_2 emission is found to be 480 kg followed by 3.00 kg of CO emission per year per telecom tower.

The total electrical energy production from the Model V is found to be 10,281 kWh/year with DC primary load consumption of 8176 kWh resulting an excess of electricity 1278 kWh/year with no capacity shortage.

4.1.6 HOMER Output Analysis for Model VI(WB)

This model of telecom load 22.4 kWh/day conveys a NPC $312,891.60. Since the Model VI uses only wind system. Though assumption is that the energy to power BTS is enough obtained from wind system which seems ideal for the selected site.

4.1.7 HOMER Output Analysis for Model VII(GB)

This model of telecom load 22.4 kWh/day and diesel price $1.10/liter conveys a large NPC $127,182.60. It reveals that a telecom tower powered by GBS consume 4084 liters in a year. Average fuel per day 11.2 liters and average fuel per hour consumption is 0.466

liters. CO_2 emission is found to be 10691 kg followed by 66.7 kg of CO emission per year per telecom tower.

4.1.8 HOMER Output Analysis for Model VIII(DG)

This model of telecom load 22.4 kWh/day and diesel price $1.10 /liter conveys a large NPC $502,363.30. It reveals that a telecom tower powered by GS consume 22,174 liters in a year. Average fuel per day is 60.8 liters and average fuel per hour consumption is 2.53 liters. CO_2 emission is found to be 58,048 kg followed by 362 kg of CO emission per year per telecom tower

4.2 Selection of model

Among output analysis of above all defined Models. Since weather condition is unpredictable so for selecting hybrid model the backup power is must for selected site. Renewable energy (solar, wind) alone may someday be inappropriate to power BTS. So hybrid model with component only solar and wind seems to be ideal for the case of selected site. Generator system model has no storage component. Storage of power generated from fuel is required for unpredictable case, to operate BTS. Hence this model also seems to be inappropriate.

So for the real case analysis, the selected models that could be appropriate for selected site are SWBG, SBG,WBG,GB.

4.3 Comparison of response of selected Hybrid Models

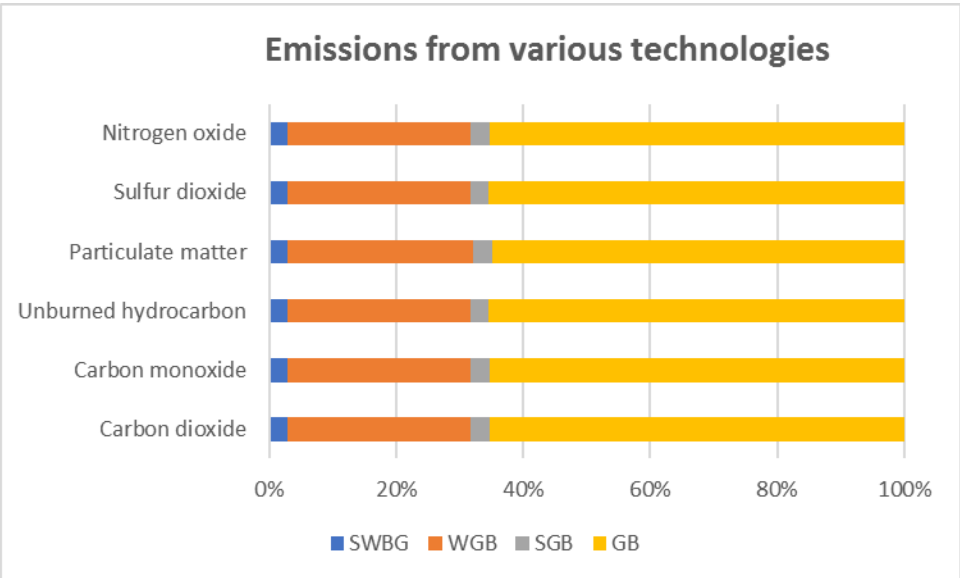


Figure 76: Emissions from Various Technologies

Emission of pollutants from Model SWBG and SGB is least and Emission from GB is most. Emission of pollutants from WGB is more compared with SWBG and less compared with GB.

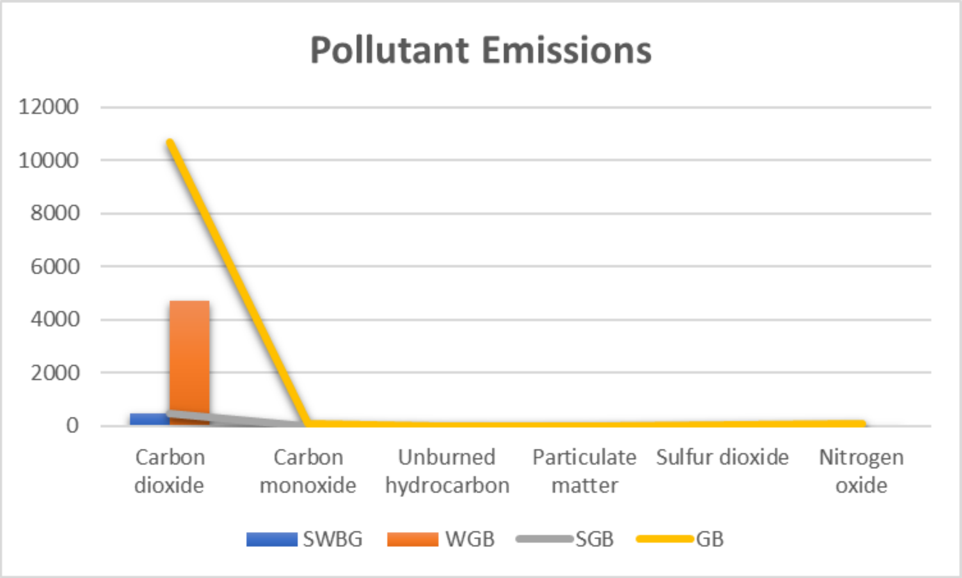


Figure 77: Emissions of Pollutants from Various Technologies in Kg/Year

All selected models emits harmful GHG gases. Among all GHG gases emission of carbon dioxide is maximum for all model. And among the selected models GB has highest emission of carbon dioxide and other all pollutants and least carbon dioxide emission is from model SWBG. These pollutant emissions has direct impact to climate.

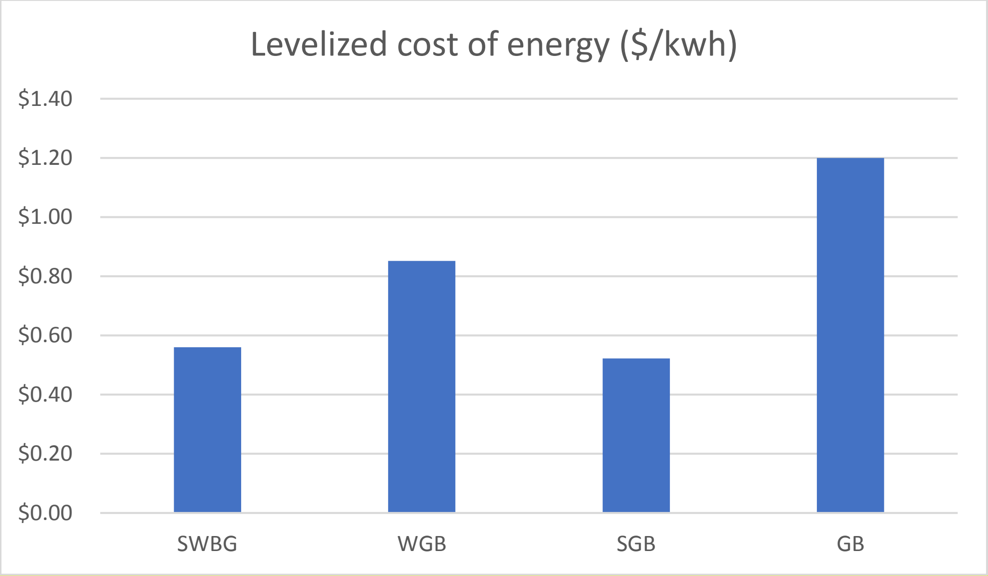


Figure 78: Levelized cost of energy

Levelized cost of Model GB is maximum. Model SWBG and SGB has almost same

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levelized cost.

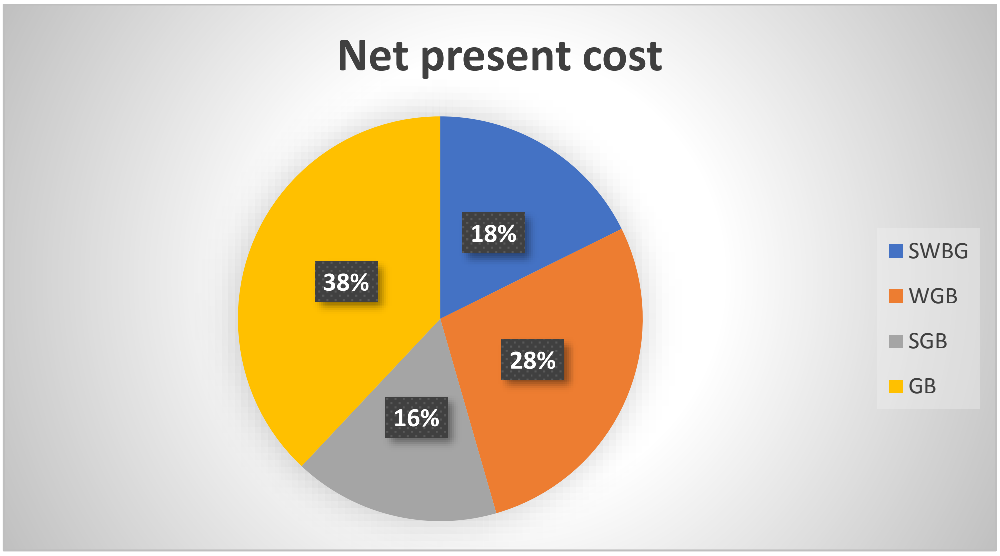

Figure 79: Net Present Cost

Net present cost of GB is highest and SGB is lowest.

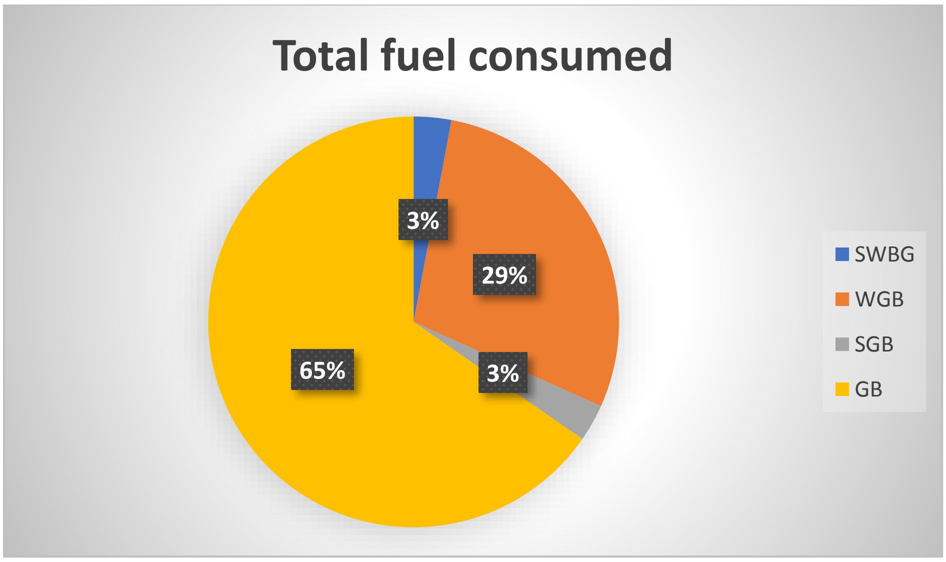

Figure 80: Total Fuel consumed

Among all models defined above, total fuel consumed is maximum for GB and minimum for SWBG and SGB.

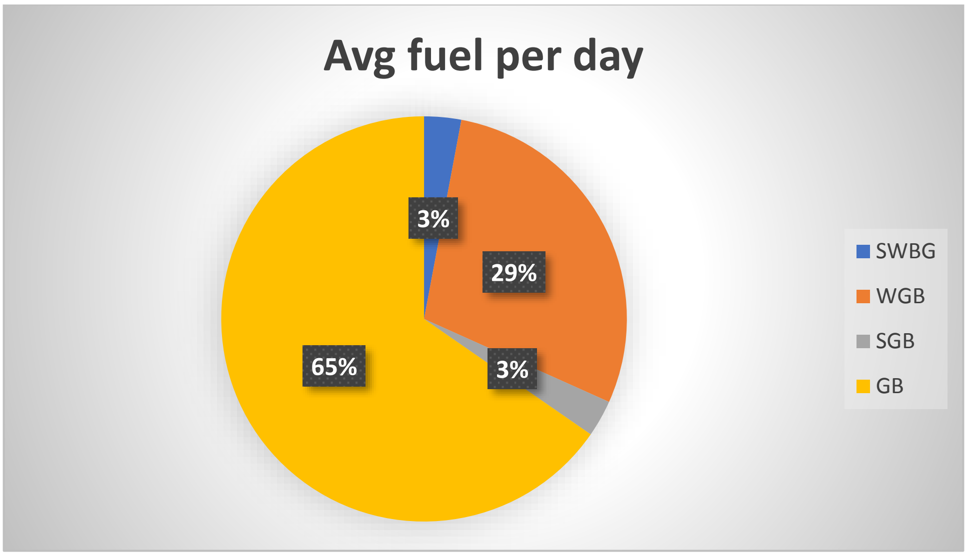

Figure 81: Average Fuel per day

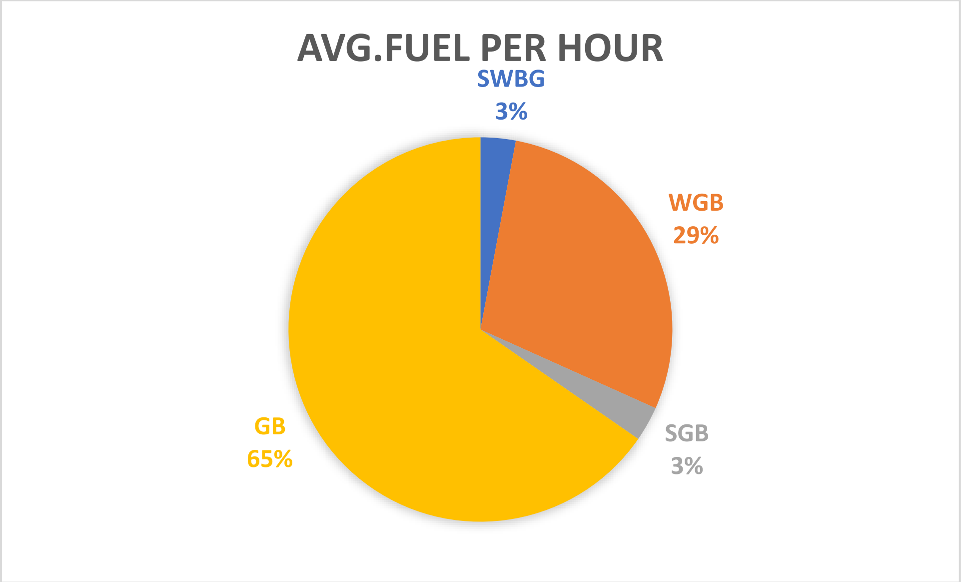

Figure 82: Average Fuel per hour

Average fuel per hour and average fuel per day is maximum for Model GB and minimum for Model SWBG and SGB.

Among selected models GB and WGB has highest emissions pollutant.. Also the levelized cost, Net present cost, average fuel per hour and average fuel per day also are of highest amount.

4.3.1 Analyzing the models in context of Environment, Economics and Energy

From ecology point of view the emissions of pollutants from hybrid Model GB and Model WGB is highest in comparison with hybrid Model SGW and SWGB as shown in Figure 76 and Figure 77. For green telecom system the emissions of pollutants from technologies should be least and should use renewable energy. The hybrid Model GB has no renewable energy so the emissions of pollutants from the Model is maximum. Hybrid Model WGB uses wind as renewable energy to power BTS but for the site that is selected the energy from wind is not that much sufficient to power BTS so the generator is run most of the time. Hence the emission of pollutants from this Hybrid Model is much. Thus from environment point of view these hybrid model are rejected.

From economy point of view net present cost of hybrid model GB is maximum and the hybrid model WGB also has high value as shown in figure 79. The levelized cost of these hybrid model is also high as shown in figure 78. So from economy point of view also these hybrid models are rejected.

From engineering point of view Hybrid Model SWGB seems to be appropriate for selected site. As all the technologies are bonded together, there will be no case where power to operate BTS be insufficient.

4.3.2 Sensitivity Analysis

Sensitivity Analysis of Model SWGB and SGB

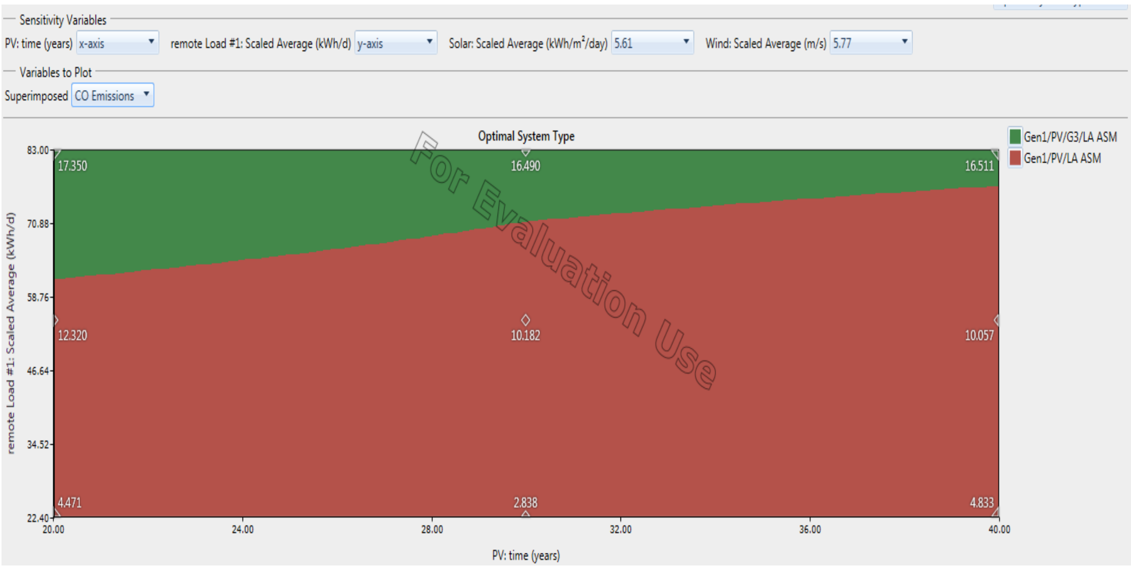

Figure 81: Sensitivity graph with superimposed variable CO

Figure 82: Sensitivity Graph with superimposed variable CO_2

Sensitivity graphs of system is based on sensitivity variables PV time(years) x-axis ,remote load scaled average(kW/d) y-axis, solar scaled average(kW/m^2/day) 5.61and wind scaled average(m/s) 5.77, superimposed variables are CO , CO_2. The graph is for SWBG and SGB. With increase in PV lifetime, the remote load can be handled more by BTS. Also Load handled by model SWBG is more compared with SGB if diesel consumption is same for both. The longer the time hybrid model is run more will be the emissions of GHG gases.

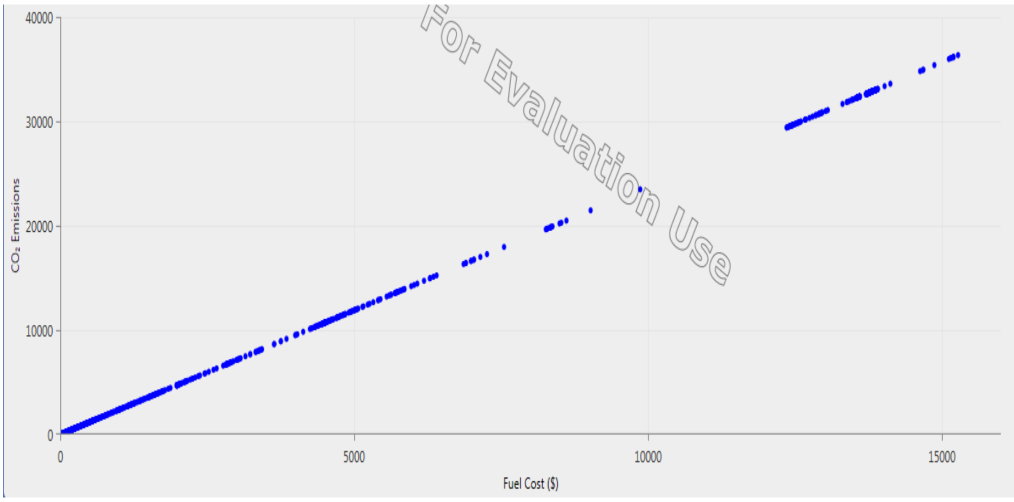

Figure 83: CO_2 Vs Fuel Cost Graph

CO_2 emission and fuel cost has linear relation. Emission of CO_2 increases with increase in consumption of fuel and increase in consumption increases cost.

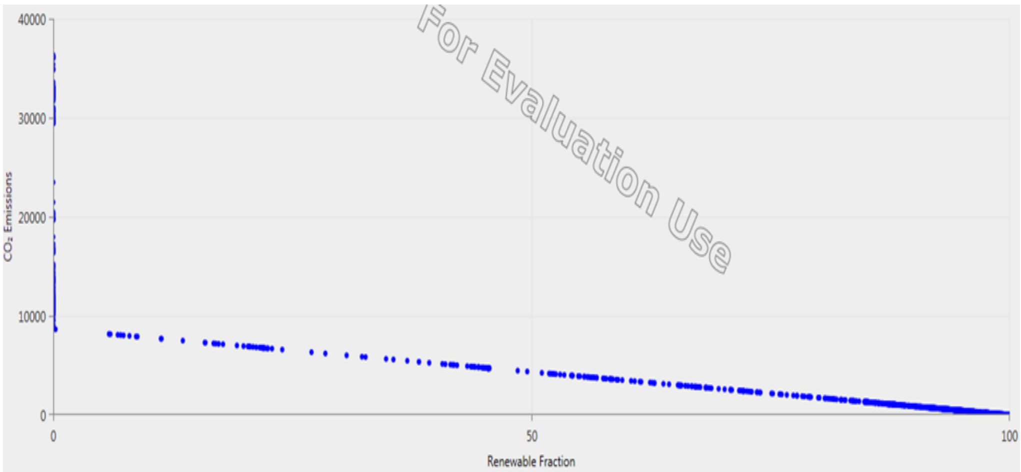

Figure 84: CO_2 Vs Renewable Fraction graph

CO_2 emission decreases with increase in uses of renewable energy.

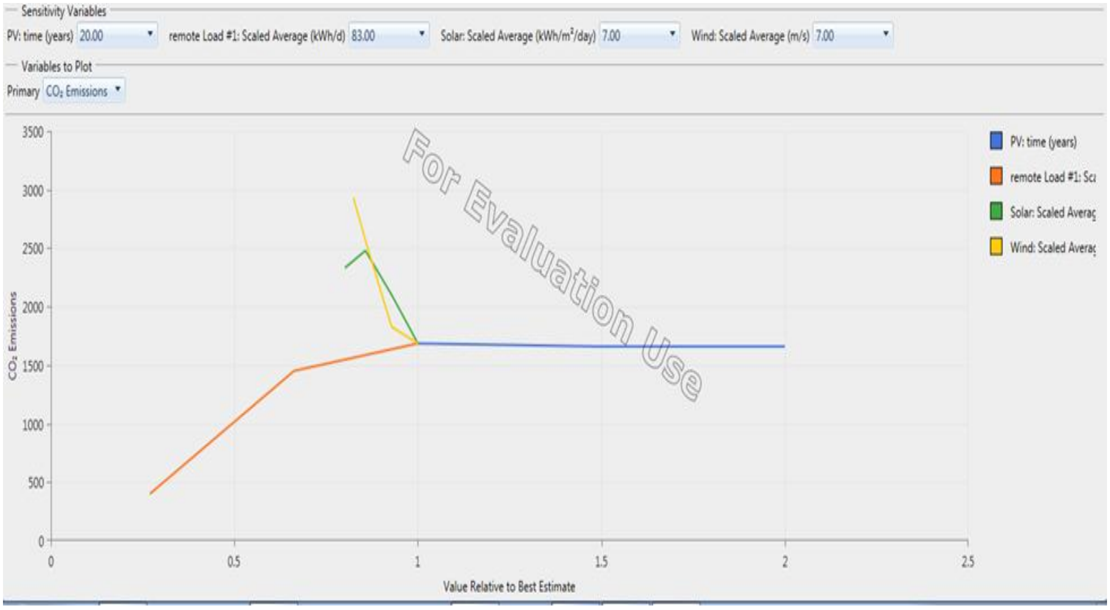

Figure 85: Sensitivity Graph

For sensitivity analysis PV time(years) is 20, remote load scaled average(kWh/d) is 83, solar scale average(kWh/m^2/day) is 7.00 and wind scaled average(m/s) is 7.00. It is seen that with increase in remote load power required by BTS increases and if this BTS is operated through diesel then CO_2 emission increases. The use of renewable energy for BTS reduces CO_2 emission. Power from PV is good enough throughout its lifetime. The reason for increased GHG, mainly CO_2, is because of the increased energy consumption which results in emission of pollutants.

4.4 Limitation of the study

Every research work has its own limitations and boundaries as per the specificity and the scope of the work. Following points are undertaken as some of the limitations of my thesis study.

- The focal point of green solution is to power remote telecom base station tower with possible renewable energy technology options, it did not talk about greening whole telecommunication system.

- The base year energy consumption data are calculated best fitted with some sort of assumptions with reference to contemporary articles and official reports.

- This study did not compare the cost economics of the solar and/or solar-wind hybrid system with grid powered telecommunication system.

- The dynamic performance of system with its components and other random parameters like seasonal variances are not taken for optimal sizing and analysis.

- The current price of the system components are taken from their corresponding web sources on the basis of contemporary research articles.

- Cost details of other equipment (charge regulator, charge controller and solar wind hybrid controller) are not included. They are supposed to be embedded with associated system estimation. Transportation cost and other miscellaneous are not considered for HOMER models developed for this particular study.

-This study is not a professional work of researcher, which is based upon the data collection and short-term field work for the partial fulfillment of the requirement for the Degree of Master of Science in Engineering.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this paper, an up-to-date review of different technology solutions for off-grid BSs in Dolpa (Nepal) was presented. HOMER was used as a simulation tools to test the most feasible RET solution configuration in powering remote telecom towers of Dolpa (Nepal), where there is no grid availability. The key aspects in choosing and designing appropriate technology solutions for the BSs were discussed accordingly. By assessing all possible eight technologies and analyzing them from techno-economical and environmental aspects, it was found that hybrid model that solely depends upon renewable energy (like hybrid model SWB, SB, WB) seemed to be ideal for selected site. Hence, were rejected. Hybrid model WGB and GB for system with telecom load 22.40kWh/day had emissions 4708kg and 10691kg of CO_2 per year per telecom tower respectively which was highest in comparison to rest of models. Also Net Present Cost and Levelized cost were $93,273.63 and 0.82($/kWh) respectively for WGB and for GB Net Present Cost and Levelized cost were $127,182.60 and 1.20($/kWh). These costs were also highest among all of rest models. Hence these models were rejected and concluded as inappropriate model for selected site. Among remaining models (SWBG and SGB) sensitivity analysis was performed. It was found that load handled by model SWBG is more compared to SGB if diesel consumption was same for both. Also, diesel consumption by SGB is higher compared with SWBG if load to be handled was kept same.

Hence SWGB for real case analysis was selected. This model consumed 185L diesel in a year to fulfill the shortage of power required by BTS in unpredictable weather condition. Among total production 65.30% of energy was from PV, 30.7% of energy was from wind system and only small fraction of energy was from generator. Hence renewable energy fraction for this model was 94.4% of total energy. CO2 emission found was 484 Kg per year per telecom tower. NPC is $59,163.93 for the system with load 22.40 kWh/day and levelized cost was 0.506 ($/kWh).Thus it is concluded that hybrid model SWGB was found to be best optimized technology to power BTS for selected site.

5.2 Recommendations

After completion of the research following are the recommendations for further work:

- In this work, the demand side management for telecom towers could been analyzed using LEAP and could be modelled to examine a supply side management strategies with new technology penetration and efficient power sources.

- The model could be developed with more advanced tools like ARMA, Markov Transition and with Artificial Intelligence also.

- A real time remote monitoring and control software could be implemented to track energy demand with better optimization techniques like, DG scheduling, PV array tilting, wind turbine speed control, battery bank state of charge monitoring etc.

- This type of work can further processed in residential application with GHG mitigation strategies.

- Since, the HOMER simulation is too slow for increasing number of decision variables, the computation process can be reduced using several newly evolved optimization techniques like artificial neural network and generic algorithm in future.

- Other renewable energy sources like pico hydro for possible remote area can also be evaluated in the context of Nepal.

- This thesis work could be further with financial and risk analysis for various models. On the other hand, a reliability analysis could be done whether the power production from RET system met the actual demand or not throughout the project life with accepted level of certainty.

REFERENCES

___. (2010). *Hybrid Wind/Solar Power for Rural Telephony Green Solution to Power Problems.* Feasibility Report on Non-conventional Energy to Power Rural Telephony.

Alternative Energy Promotion Center, AEPC. (2008). *Solar and Wind Energy Resource Assessment in Nepal.* United Nations Environment Program, Global Environment Facility, Khumaltar, Lalitpur, Nepal.

Alternative Energy Promotion Center, AEPC. (2008). *United Nations Environment Programme, Global Environment Facility, Solar Wind Energy Resource Assessment in Nepal (SWERA).* Khumaltar, Lalitupur, Nepal: AEPC, GoN (Ministry of Environment, Science and Technology).

Amanna, A. (2010). *Green Communications.* Annotated Literature Review and Research Vision, Institute for Critical Technology and Applied Science at Virginia Tech (ICTAS), Virginia.

Arnold, O. (2010). Power Consumption Modeling of Different Base Station Types in Heterogeneous Cellular Networks. *Future Network and Mobile Summit 2010Conference Proceeding.* Stuttgart, Germany: IIMC International Information Management Corporation.

Asian Development Bank,(ADB,2015). https://www.adb.org/sites/default/files/ institutional-document/182852/adb-annual-report-2015.pdf

Auer, G. (2011). How Much Energy Is Needed To Run A Wireless Network? *IEEEWireless Communication, Technology for Green Radio Communication Networks*.

Belfkira R, Zhang L, Barakat G. *Optimal sizing study of hybrid wind/PV/diesel power generation unit*. Solar Energy 2011; 85: 100-110.

Center for Energy Studies, CES. (2000). *Renewable Energy Perspective Plan ofNepal, 2000-2020: An Approach.* Lalitpur, Pulchowk: Institute of Engineering.

Central Bureau of Statistics, CBS. (2012). *National Population and Housing Census2011 (National Report).* Kathmandu, Nepal: Government of Nepal, National

PlanningCommission Secretariat.

Dahal, M. S. (2010). *Evaluation of Photovoltaic System in Nepal Telecom in BagmatiZone.* Thesis Report, Institute of Engineering, Department of MechanicalEngineering.

Dufkova, K. (2011). Energy Savings for Cellular Network with Evaluation of Impact on Data Traffic Performance.

Energy Commission. (2006). *Energy Demand Sectors of the Economy.* Strategic National Energy Plan (2006-2020) Annex I of IV, Ghana.

European Renewable Energy Council, EREC. (2012). *Energy Revolution.* A Sustainable Global Energy Outlook.

Energy and Economy Growth,EEG.(2016).https://assets.publishing.service.gov. uk/media/ 5a2696fae5274a75088c42b6/Line_36_-_EEG_PreSouth_Asia_Policy_Workshop_Report .29.09.2016.pdf

Fehske, A. (2011). The Global Footprint of Mobile Communications: The Ecological and Economic Perspective. *IEEE Communication Magazine*.

Fehske, A. J. (2011). Energy Efficiency Improvements through Micro Sites in Cellular Mobile Radio Networks.

Ferreira, P. (2003). Interfaces for Renewable Energy Sources with Electric Power Systems. *Environment 2010: Situation and Perspectives for the European Union.* Porto, Portugal. Retrieved 2010

Goel, S. (2014). Cost Analysis of Solar/Wind/Diesel Hybrid Energy System for Telecom Tower by Using HOMER. *International Journal of Renewable Energy Research, 4*(2). Retrieved 04 25, 2014

Groupe Speciale Mobile Association, GSMA. (2011). Energy for the Telecom Towers, India Market Sizing and Forecasting. New Fetter Lane, London, UK:GSMA, Green Power for Mobile.

Groupe Speciale Mobile Association, GSMA. (2012). Powering Telecoms: East Africa Market Analysis. New Fetter Lane, London, UK: GSMA, Green Power for Mobile.

Groupe Speciale Mobile Association, GSMA. (2013). Greening Telecoms: Pakistan and Afghanistan Market Analysis. New Fetter Lane, London, UK.

Han, C. (2012). Green Radio: Radio Techniques to Enable Energy Efficient Wireless Networks.

Hassan, H. A. (2013). Renewable Energy in Cellular Networks: a Survey. *IEEEOnline Conference on Green Communications (OnlineGreenComm).* Cesson Sevigne,France.

Hassan, H. A. (2014). Classification of Renewable Energy Scenarios and Objectives for Cellular Networks.

Himalayan Times. (2017).https://thehimalayantimes.com/opinion/renewable-energy-huge-potentials/

Homer.https://www.homerenergy.com/?fbclid=IwAR27UEt5UP2RQkSstKpVmmWhmoma V4lghb9kS1Ue1uyPfL8kLBsWZ5tTj8

India-Times News. (2012). Retrieved from Economics-Time: http://www.articles. economictimes.indiatimes.com/201205/news/35620263_1_bharti-infratel-telecom-tower-American-tower

Intelligent Energy. (2012). *The True Cost of Providing Energy to Telecom Towers in India.* Intelligent Energy Limited. Retrieved August 2012

Intelligent Energy. (2013). *Green Solutions for Telecom Towers: Part.* Intelligent Energy Limited. Retrieved from http://www.intelligent-energy.com

International Energy Agency, IEA. (2010). *World Energy Outlook.* IEA. Retrieved from www.iea.org

International Energy Agency, IEA.(2016).https://www.iea.org/newsroom/news/2016/

International Telecommunication Union, ITU. (2012). Final Acts, World Conference on International Telecommunications. Dubai, UAE. Retrieved December 3-14, 2012

International Telecommunication Union, ITU. (2014). *Transformative Solutions for2015 and Beyond.* ITU.

Kassam, A. (2010). *HOMER Software Training Guide for Renewable Energy BaseStations Design.* London: GSMA. Retrieved fromhttp://www.gsmworld.com/greenpower

Kaundinya, D. P. (2009). Grid-connected versus stand-alone energy systems for decentralized power-a review of literature. *Renewable and Sustainable EnergyReviews,13*.

Kavolynas, A. (2012). Possibilities to use Photoelectric Energy Sources in Microclimate System of Telecommunication Station. *Jelgava, Engineering for RuralDevelopment, 24*.

Krishna, R. (2012). *Green Energy Technology (GET) for Telecom Applications.* TEC New Delhi: DoT, Govt. of India.

Kumar, A. (2010). Sustainability in Wireless Mobile Communication Networks through Alternative Energy Resources. *International Journal of Computer Scienceand Technology, IJCST, 1*(2).

Lorincz, J. (2012). Measurements and Modeling of Base Station Power Consumption under Real Traffic Loads. *Sensors, 12*(4281-4310). doi:10.3390/s120404281

Lubritto, C. (2011). Energy and environmental aspects of mobile communication systems. *Energy, 36*(2), 1109-1114.

Maharjun, S. Assessment *of Wind Energy Potential of Nepal using Climate Model and its Future Projection.* Master's Thesis Report, Tribhuwan University, Department of Engineering Science and Humanities.

Moh, C. C. (2012). *Addressing and Understanding Climate Change Triggers in theIndian Telecom Environment.* Tata ISES 2012, Tata Teleservices Limited. RetrievedAugust 27, 2012

NASA-ASDC. (2014). *Solar and Wind Resource Data*. Retrieved from NASA Data Portal: https://www.eosweb.larc.nasa.gov/

National Renewble Energy Labarotary, NREL. (2012). *Cost and Performance Datafor Power Generation Technologies.* USA: Black & Veatch.

Nepal Energy Strategy NES.(2013).http://www.wecs.gov.np/uploaded/National-Energy-Strategy-of-Nepal-2013.pdf

Nepal Oil Corporation, NOC. (2019). http://www.nepaloil.com.np/diesel.

Nepal Telecom, NT. (2013). Nepal Doorsanchar Company Limited Annual Report 2011-2012. Kathmandu: Nepal Telecom.

Nepal Telecommunication Authority, NTA. (2014). Management Information System. *115*(67).

NepalTelcommunicationAuthority,NTA.(2017).http://nta.gov.np/old/en/component/joomdoc/Complete%20RFA%20Final.pdf/download.html

Northeastenergyefficiency,NEEP(2015).https://neep.org/sites/default/files/reports/NEEP%202015%20Business%20Plan_FINAL.pdf

Nguyen, N. T. (2010). *Barriers to the adoption of renewable and energy-efficien ttechnologies in the Vietnamese power sector.* Meteo, France: CIRED.

Okundamiya, M. S. (2014). Assessment of Renewable Energy Technology and a Case of Sustainable Energy in Mobile Telecommunication Sector. *The Scientific WorldJournal, 2014*, 13. doi:10.1155/2014/94/7281

Paudel, S. (2011). *Optimization of Hybrid PV/Wind Power System for Remote Telecom Station.* Master's Thesis Report, University de Aveiro, Department of Mechanical Engineering.

Prasad, S. (2012). *Green Networks: Transforming Telecommunications on Sustainable Energy Alternatives.* New Delhi: Bharati Infratel Limited.

Prem, C. R. (2018). *Impact of Climate Change on Solar Energy Generation in Nepal Using Climate Model.* Master's Thesis Report, Tribhuwan University, Department of Applied Science.

Product/Solar.(2019).https://www.alibaba.com/product-detail/60KW-Solar-Power-Solar-TelecomEnergy_60367025284.html?spm=a2700.7724857.normalList.22.3b7c811bBTIeDa

*Product/Windturbine(*2019).https://www.alibaba.com/product-detail/Horizontal3kw-wind-turbine-price-windwheel_60720098332.html?spm=a2700.7724857.normalList.

106.125d7f32SwrSpD

Reliance Communication. (2012). *Consultation Paper on Green Telecommunication, Reliance Communication Response to TRAI.* India: Reliance Communication.

Shreekrishna (2014). https://www.researchgate.net/publication/268152233 _Comparative_ Analysis_of_SolarWind_Hybrid_System_with_Diesel_Generator_System_in_Powering_ Remote_Telecom_Towers_of_Nepal_using_HOMER

Shrestha, J. N. (2009). Application of Building Integrated Photovoltaic Electric System: Its Contribution in Reduction of Load Shedding Hours in Nepal. *Journal of Institute of Engineering, 7*(1), 1-5.

Shrestha, R. M. (2013). Macroeconomic Consequences of Power Trade Policy in Thailand: The Computable General Equilibrium Analysis. *The 2nd Asian Conference:Energy Security and Economic Development under Environmental Constraints in the Asia Pacific Region.*

Singh, S. (2012). Green Base Stations: A Sustainable Approach in Wireless Communication Networks. *International Journal of Education and Applied Research, 2*(1). Retrieved from http://www.ijear.org

South Asian Telecommunication Regulator's Council, SATRC. (2012). *SATRC Report on GREEN TELECOMMUNICATIONS.* Kathmandu: ASIA-PACIFICTELECOMMUNITY, SATRC.

Suarez, L. (2012). An Overview and Classification of Research Approaches in Green Wireless Networks. *EURASIP Journal on Wireless Communicatons and Networking,1*(142). Retrieved from http://jwch.eurasipjournals.com/content/2012/1/142

Telecom Regulatory Authority of India, TRAI. (2011). *Consultation Paper On Green Telecommunications.* Jawahar Lal Nehru Marg, New Delhi: Telecom Regulatory Authority of India. Retrieved Februrary 3, 2011

Vinay Chamola, Pratik Narang, Biplab Sikdar, *Downlink power control for latency aware grid energy savings in green cellular networks*, *Sarnoff Symposium 2016* IEEE 37th, pp. 1-6, 2016