Department of Mechanical and Aerospace Engineering

Off-Grid Renewable Energy Solution for Village Soran, Pakistan

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Signed: Bashir Khan Date: 22.08.2019

Abstract

Pakistan is a developing country in South Asia, 62% of its population is living in rural area, of which 24% of its rural population is living off grid. The country is facing energy shortage since Independent but the shortage gap become wider and wider since 2007 and those, who are grid connected, face 6 to 7 hour blackout on daily basis. The case study selected is located in rural area, North West of the country and is off grid. Soran is in District Mohmand (previously known as Mohmand Agency) K.P.K of Pakistan. An energy system was designed for the rural village with the consideration of the local population and resources. A methodology was adopted and used throughout the investigation to make sure work is completed efficiently.

The methodology is focused on literature review, Microgrid for rural area, energy storage for renewable supply. The load profile was estimated on the energy consumption of similar size and culture in same district. The demand profile was estimated and used to product the model.

Literature review states issues related to rural electrification through off grid from renewable sources. The energy consumption was not available so followed a survey method of similar size village in same culture and considered will use power in same manner if provided. Homer, computer software, optimization tool was used to model different scenario and see the effect of variables and to identify the ideal system for the village.

The ideal or most appropriate system for village Soran of District Mohamnd of K.P.K of Pakistan-constitutes of PV, Wind Turbine, Batteries and Diesel generator as back in for insufficient power produce or rise in demand and to provide stability to the system.

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1. Introduction:

1.1 Background

Electricity is fundamental and basic right and prerequisite of each citizen of a country; it is also an essential element for industrial growth, agriculture and socio-economics development. In most areas of the world where due to lack of local electrical power these areas are also less industrialized as compared with that of zones having ample quantity of electric power (Nounia, et al., 2007). According to a report from 2010, almost one out of five individuals; that constitutes nearly 1.3 billion, in the world are deprived from a basic need of electricity. 21st century is providing nearly every kind of advancement; evolution and revolution, still to provide power: mainly electric power, with maximum reliability and minimum cost, is one of the biggest challenges being faced. Electrifying of the rural areas: mostly termed to be as agricultural or considered out of city, are still consider to be done by grid-extension method (Bhattacharyya, 2012). Electrification of rural areas has been, till date, implemented by the help of extension of the grid. But due to a number of problems faced by such exiguous populated areas the installation of grid extension method, for electrification, can't be accomplished. Extending of electricity grid to such areas can be encountered by either financially infeasibility or impracticability. The electrification of rural areas can't be implemented by grid because of power losses; high transmission and distribution lines and disruption in power. Power can be transmitted to remote areas by means of extinction of high transmission and distribution lines. Technically the distribution of power consists of 3 major factors i.e a) cost of electric power generation at the station, b) cost of lines by means of which electric power is transmitted and c) cost help on distribution. As the prices of petroleum are beyond approach and the cost on transmission line is snowballing, plus the reduction of carbon dioxide is under consideration, the use of renewable electric power is highly recommended (Hafez & Bhattacharya, 2012). As the demand of electric power is increasing exponentially, the resources are supposed to meet the demand. In this regard renewable energy, because of its low cost and environment friendly attributes, is catching attention. For implementation of isolated power system, renewable energy because of its cost effectiveness is gaining attention.

Since the oil crisis after 1970s, electric power production by means of solar or wind as renewable energy sources have been highly under consideration and preferred (Deshmukha & Deshmukh, 2006). One of the necessities from a hybrid renewable energy source is the storage of excess energy to make certain incessant power flow. Installation of Solar panels: made of solar photovoltaic cells, and micro hydro power are such renewable energies technologies which are mostly considered crucial. But due to the limitation of resources, like for hydropower water is indispensable, or the problems arising from the changing of resources, these technologies may be unable to provide efficient power to customer. In order to beat the problems faced by depending on renewable energies sources, mentioned former, a hybrid system need to be design. The problems caused from these technologies include the oversizing of system which directly increases the cost and its periodical nature. Because of the complexity of hybrid system, it is gaining little attention, particularly in rural areas which are already deficient in energy resources.

Pakistan is a developing country and 6^{th} largest nation in world among which 51 million people or 24% of its population is living without electricity. (IEA, 2017). Pakistan energy demand is on rise and most of its northern part is not electrified yet and Pakistan is facing energy shortfall at the moment and the short fall is persistent since 2007-08 (Khalil, 2014). The total power generation is consisting of 67% thermal generation and 29% of hydro and the reaming is from

Nuclear (AEDB, 2005). Pakistan consists of five provinces Sindh, Punjab, Baluchistan, Gilgit Baltistan and K.P.K (Khyber Puhtoon Khwa). The K.P.K is in North West and recently FATA became part of it. The village of Soran is in District Mohmand previously known as the Mohmand agency since independent and is much of the area is off grid especially the area near to Afghanistan.

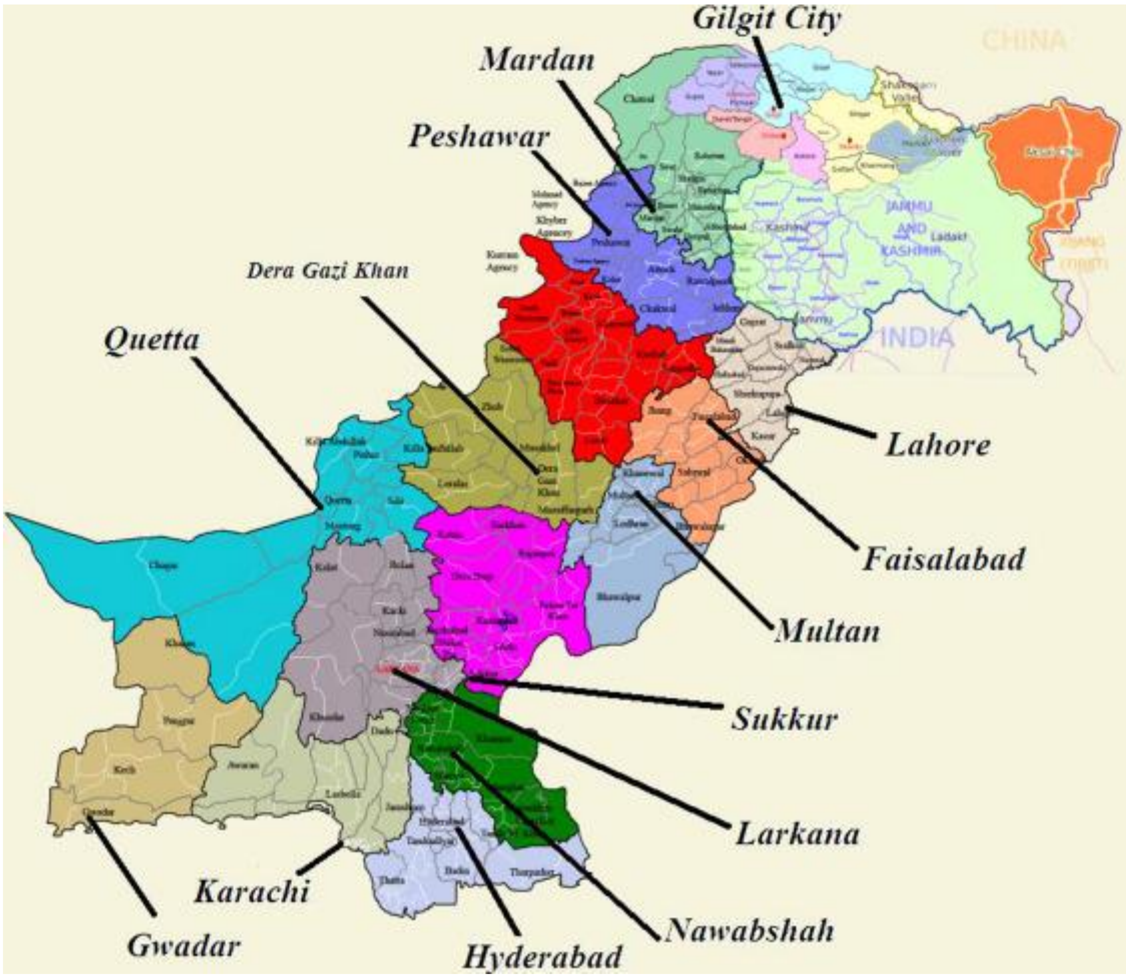

Figure: 1

1.2 Problem statement:

Most of the northern area and western desert of Pakistan is yet not electrified. Power system of Pakistan depends on fossil fuels both in private sector and state owned power plants. About 67% of generated power comes from carbon emitting natural gas, liquid fuel and coal. The supply of natural gas is not sufficient to meet the demand. Current gas production capacity in Pakistan cannot support domestic needs as well as wider electricity generation for the country. The existing reserve of oil and gas will be exhausted very soon. At the same time worldwide there is a demand for clean and sustainable energy. The need for developing renewable sources of energy like solar, wind, biomass, has a greater sense of urgency. As a South Asian country, Pakistan is endowed with solar energy and wind energy. In this context solar and wind energy is an affordable and secure energy for off-grid areas of northern part of the country. But the present share of renewable energy for electricity production is negligible of the total. Major population of Pakistan lives in rural areas. There is strong demand for power availability in remote villages. Those areas which are off grid do not have choice but to rely on unreliable and unhealthy source like kerosene oil and traditional way of burning wood. Pakistan has embedded with plenty of solar energy. The country has much potential to be a solar electricity-rich country. Institutional, financial and technological capabilities act as important factors for reaching a desired level of solar electricity production and utilizations. But have lack of information and integrated research in this field. (Khalil, 2014)

Microgrid is very successful in India for providing electricity to rural India but we have not seen such trend in Pakistan for solving the electric issue. (Khan, 2018)

1.3 The objectives of the study are as follows:

The aim of the report is to design a sustainable off grid energy solution from a combination of renewable technology in Village Soran Dara District Mohmand K.P.K (Previously Known as FATA).

The system should meet the following criteria:

- The power supply should run autonomously:
- It should have a combination of two or more renewable sources:
- It should be financially sustainable:
- Lowest possible emission of CO_2 to atmosphere:

The Village selected for the mentioned design is Soran Dara in District Mohmand previously know Mohmand agency part of FATA in North West of Pakistan.

The scope of study is confined to discover a combination of; hybrid, of renewable energy technologies, from the resources which are easily accessible in the remote rural areas, which have the potential to generate a home run power system. Hybrid energy system consists of two main sources that are a primary source which is a renewable energy source plus a secondary source which may not be a renewable energy source (Khan & Iqbal, 2004).Additionally the scope of study is also confined to evaluate whether the design hybrid system do match the requirements, of being reliable with minimum cost, or not. In order to meet the former mention objectives, it is mandatory, to find a rural or a remote area, which in this study Village Soran is chosen that is a faraway village in province KPK, Pakistan. In that remote village, for analyzing the hybrid system, few more parameters are to be considered, including, to find the energy required, go for and evaluate the resources, to design a model for renewable energy technologies (RET) and weather the off grid is cheaper in comparison to grid extension.

The structure of the report is as follows:

Chapter 2:

In order to understand and get background knowledge of off grid energy solution for rural communities, literature review was conducted. The literature review was mainly focused on those countries which have similar sort of environment and income level like that of Pakistan.

For this purpose most of the South Asian countries, India, Bangladesh, Sri-lanka and other like China and Far East Asian countries.

Chapter: 3:

Chapter three describes the reason of selection of Microgrid or off grid solution for the rural area over grid extension and the selection of energy storage for off grid solution.

Chapter: 4:

In order to solve energy problem for rural area from renewable energy source, a renewable source need to be investigated in the vicinity. The climate data for the country and local area were investigated to find suitable solution. The climate data of the area then advised the respective renewable technologies to be used for the solution.

Chapter: 5

Village visit should be carried out in order to get the data for energy consumption but was not possible due to tight schedules, so most of the data was collected through phone and through personal contact. A survey sheet was designed for the specific questions. The survey focused on energy consumption pattern and also on appliances they use.

Chapter: 6

The selection of software for the design of off grid energy for rural area was done by tool assessment. The Homer software was selected because it was able to design a Microgrid and provided optimized results in respect of financial and emission respect.

Chapter:7

A Microgrid was design by using Homer software. The design model was run for simulation on present cost of renewable technology and present price of diesel and results were produced similarly results were produce for future cost of renewable technology and future price of diesel.

Chapter: 8

Result from simulation are analyzed for four criteria of the ideal or near ideal off grid energy solution for rural communities. In those results the system meets the power demand, cost of energy, renewable penetration and emission of green house gases. The one with most least expensive and provide sustainable energy with less emission was selected a possible solution for rural area energy supply.

Chapter: 9

The analysis was done on results and future work was identified and conclusion was drawn.

2. Literature review

The literature review is to support the methodology used in the investigation and a source of information for comparing the results obtained and background knowledge.

The literature review in the investigation focused on a number of components in more details in research.

- Consumption of electricity or energy in rural area in comparison to urban area

  There are number of factors that deprive rural area from electricity and one of the main factors is the economic approach, played central role, will continue its affect in any future project. Some of the areas that are able to counteract the narrative developed by factors to keep rural area off power are the technological maximimsing energy supply, reducing cost of energy supply, minimizing social welfare impact and reduce environmental impact (Cherni, et al., 2007).

  The rural electrification through grid extension and other means is effected by the low return on huge investment and some other factors like, low load factor, low voltage, regular power supply disturbance, sparsely population and huge in front investment. (Ganthia, et al., 2018) (Kumar, et al., 2017)

  A research was carried out by Miah et al in a village of district Chatgong Bangladesh regarding energy consumption pattern. According to their finding 70% of energy of the total energy consumed in household and the same pattern is in Nepal, India and Myanmar. According to their finding energy consumption in Bangladesh and other south Asian countries energy consumption is related to level of income of household. The research conducted on different type and income level housed concluded that:

  - The use of energy consumption (Biomass, candles) increases as the level of income rose.
  - Most of the houses used wood and other agriculture waste for cooking and other daily need of energy.
  - A very few numbers of houses consumes modern source of energy due to the high cost.
  - The selection of energy source for daily activity was not only related to level of income but other factors also influence it.

According to their finding a number of factors influenced energy consumption in rural area but the major factors are level of income, family size, literacy level and types of house. (Miah, et al., 2010).

The rural energy data in developing countries is not available so Mustonen S.M carried research in Lao people's Democratic republic in a village which has source of energy in form of renewable energy and a diesel generator in back up. The data regarding the village was collected by interviews of the village residents and some of the data from was collected through some of the organization relevant to that village particularly. The data collection through interviews has three basic questions:

- ✓ The first question was regarding household activities and the time of activities;
- ✓ The second was regarding household energy consumption and types of fuel;
- ✓ The third and final question was regarding the time of lighting and any change with respect to season variation.

From data collection through questioners concluded that most of the people according to their level of income use either biomass or other means of modern source for cooking similar finding like Miah et al have in his research (Mustonen, 2010).

Rural area of developing world meets their lighting necessity through burning kerosene oil in lateen and biomass far cooking and heating according to Kaygusuz finding (Kaygusuz, 2011).

People also have multiple choices in developing countries for the selection of energy sources (compressed natural gas, liquid petroleum gas, Charcoal, wood, biomass and kerosene oil). The selection is based on purpose of use like for cooking, lighting and boiling water (Jan, et al., 2012)

2.1 Off grid or decentralized or micro grid and renewable energy

In India, a comparative study of cost by electrification of a rural health center was carried out between the power provides by grid and that of power generated by fuel cell-based, by using HOMER simulations. The health center was located at almost 44 km from the grid. From the result of simulation it was understood that the cost of generating power from a fuel cell is cheaper than that of power obtained from grid. Limitation of study is that it is only bound to analyze the simulation for a rural health center only (Munuswamy, et al., 2011).

A case study, in Sri Lanka, was conducted by Gilver and Lilienthal who showed that generation of electric power from a hybrid of photovoltaic cells and diesel is much more cost effective than that of using only photovoltaic cells for home run system (50 W PV and batteries for storing power). Though the focus of this study was not the productive use of power, still the results obtained were from the simulations of an individual household with a base load of 5 W leading to daily average of 305 Watt-hour by taking the peak of load as 40 Watt (Givler & Lilienthal, 2005).

A theoretical research was carried out by Hafez and Bhattacharya; they designed a model of micro grid system in which they assumed the base load of 600kW, peak load at 1183kW and daily electric supply needed to be 5000kWh per day. Model consisted of solar, wind, diesel and hydro generation of power. But because of the purely theoretical design, the assumptions were unrealistic for a number of off-grid areas in developing countries (Hafez & K Bhattacharya, 2012).

Lau, in Malaysia, studied and analyzed the practicality and feasibility of a hybrid system in a remote area using HOMER simulations. Study was a theoretical approach of modeling a community of 40 households with maximum demand of electric power to be 2 kW each. Base demand was considered to be 30 kW as whole. Limitation of this study is that the theoretical model design by Lau is only applicable for Malaysian condition (Lau, et al., 2010).

Patel and co researcher model an electric supply from locally available renewable sources, biomass, biogas, wind and solar PV. The model meets the electric load profile of village with cost effective compare to grid extension and with reliability all over the year. The sizing of the different component has been done in such a way so that can meet the four different load profile of the year (Patil, et al., 2011).

Ding, Lee, Liu and Wetz have mentioned a couple of options in their research to improve energy poverty of remote area by means of Grid extension or to build a micro grid or mini grid for that locality in order to supply electricity. They have further iterate in their research that micro grid have advantages over grid extension. Similarly Nguyen also pointed out the advantages of micro grid over grid extension in his research. The mentioned advantages of micro grid over grid extension are:

- Capacity and energy cost are low
- Creation of localized job and businesses

- Independent of fuel because of Renewable technology
- No pollution due to renewable technology
- Transmition and distribution cost are significantly low compare to grid extension

The International Renewable energy Agency (IRENA) has mentioned some of the advantages of off grid over grid extension energy solution. The advantages are:

Economical advantages:

- The off grid is very cost competitive
- It generates local jobs
- It develop skills
- It provide access to modern energy

Human development

- It empower local community and overall wellbeing
- It provide sustainable live hood to local community
- It provide access to public services locally

Technology

- Proven technology for off grid solution and adaptable
- Scalable technology according to local energy demand
- Innovation in both finance and delivery model

The above advantages mentioned in IRENA report of 2019 (IRENA, 2019).

Bhoyar and Bharatkar mentioned in their research that micro grid could be the possible solution for rural area electrification in future because it will enable the rural communities to control their energy use and reduce the emission to the environment through a new and innovative way of generation and management. According to their research micro grid provide improve reliability and power quality (Bhoyar & Bharatkar, 2012). Micro grid have an additional benefit for rural communities which enable the rural communities to be grid connected later if wish by rural communities as mentioned by Ding, Liu, Lee and Wetz (Ding, et al., 2013). Bhoyar and Bharatkar mentioned the concept of micro grid which includes a network of small scale distributed energy resources, generation and storage and have the ability to response to dynamic changes in energy supply through co-generation and demand adjustment (Bhoyar & Bharatkar, 2012).

Ding et al researched that renewable energy has the potential to provide most sustainable and cost effective energy to remote or rural area. Similarly Akikur et al have conducted research in more delicately to find the reason of renewable energy potential have not been exploited yet. His finding shows that the initial capital cost of renewable technology is higher that of fossil fuel and due to this world still rely on fossil and 80% of world energy comes from fossil fuel (Akikur, et al., 2013)

Similarly Urmee and her co researcher also pointed out that the main reason for not using renewable technology for rural electrification is due the high cost of equipment (Urmee, et al., 2009).

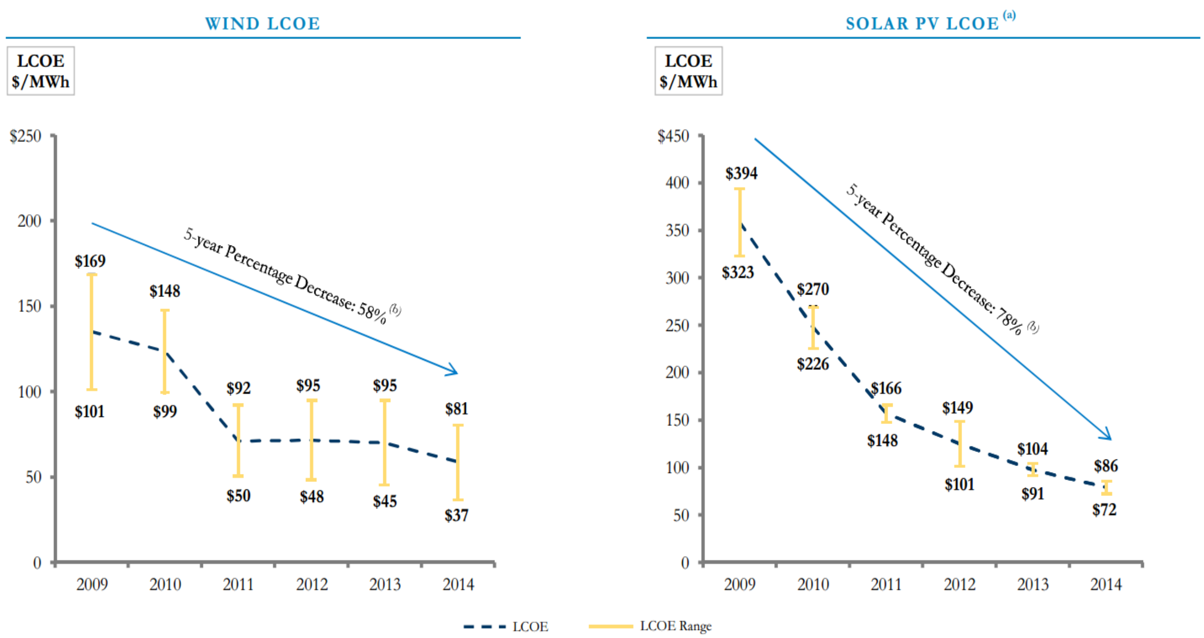

Fig: 2 Solar and wind LCOE drop (Naam, 2014)

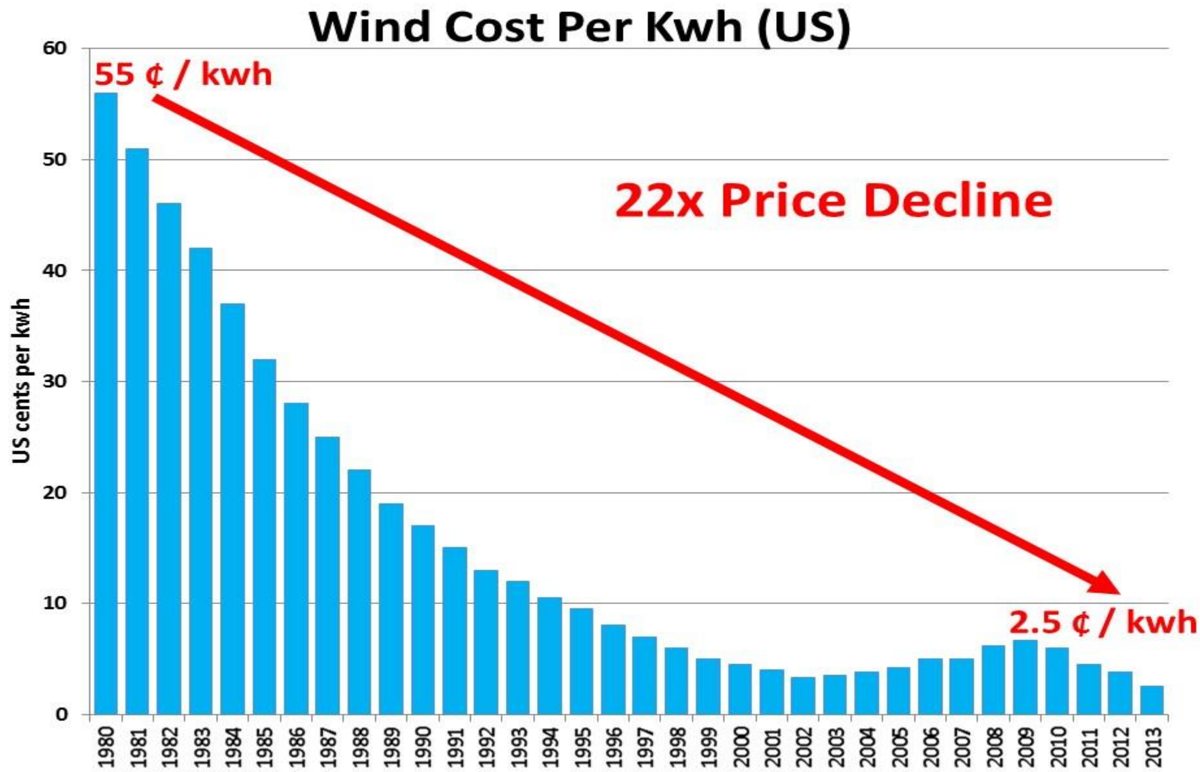

Fig: 3 Cost of wind energy per Kwh since 1980 trend (Naam, 2014)

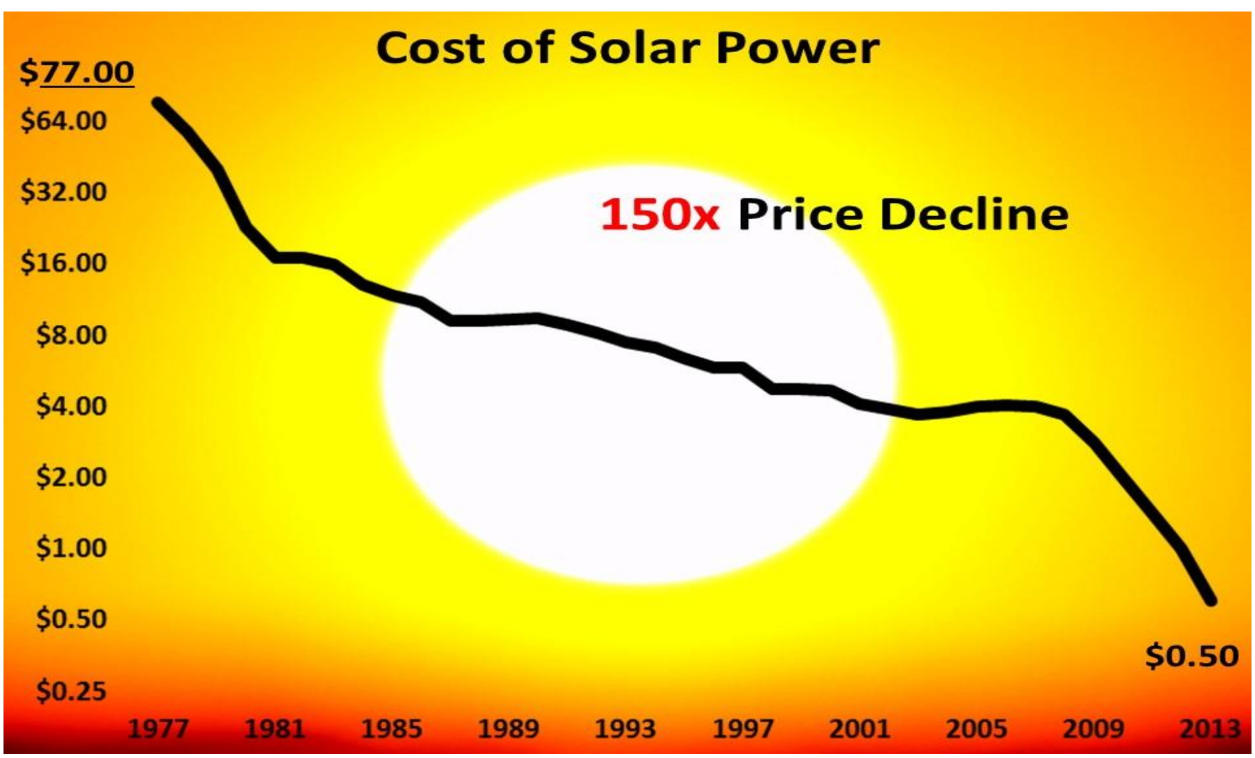

Fig:4 Cost of solar energy drop since 1980

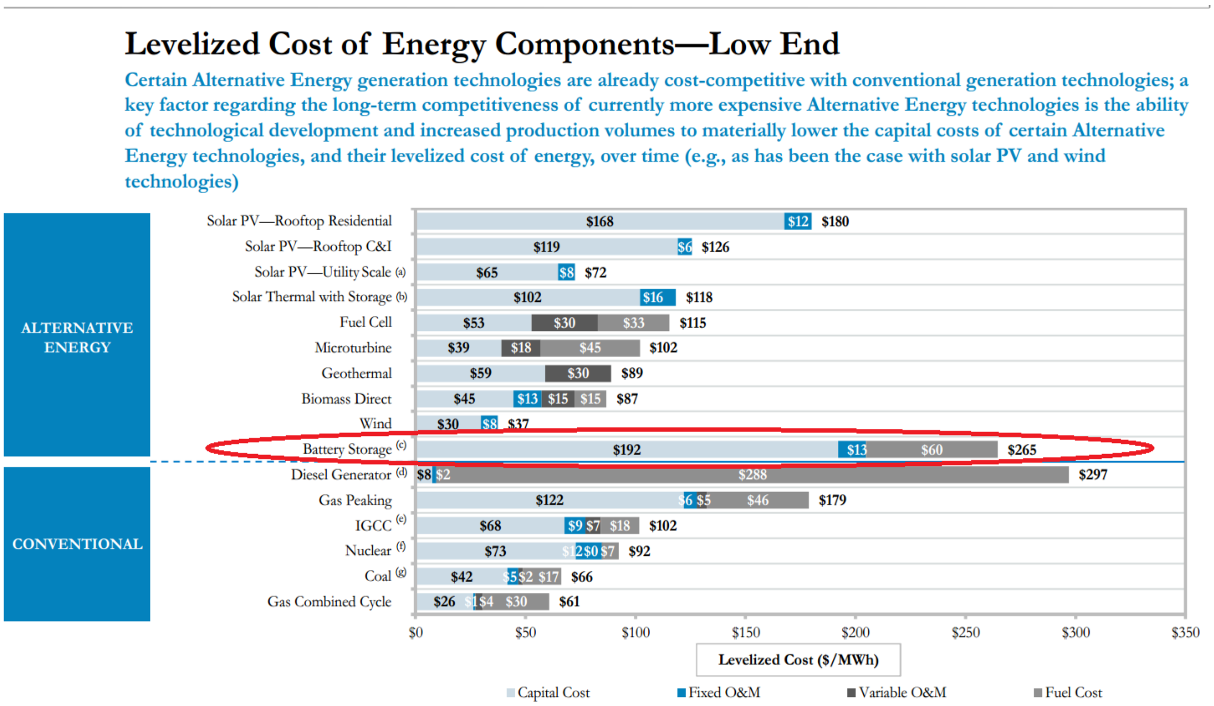

Fig: 5 LCOE from renewable compare to fossil fuels

The dynamics changes in cost of solar and wind technology has been discussed by Rameez Naam. The cost trend for wind and solar energy technologies has shown in figure 2, 3 & 4. The cost of wind energy dropped by 5% since 1980 and hope this trend will continue in future as more research and investment committed. The same cost reduction trend in solar energy technology also continues but at higher rate than wind energy technology due to the more investment and research committed. The reduction in cost of renewable energy technology especially in solar and wind will increase the applicability in poor communities of world and tin turn will increase the share of renewable energy in world power requirement and will reduce the consumption of fossil fuel. The cost of fossil fuel will be higher in future due to the depletion of fossil fuel resources. Although currently 80% of world energy requirement is met through fossil fuel but will soar in price so the power generation from renewable energy technology will be beneficial (Naam, 2014).

Similarly IRENA (International Renewable Energy Agency) discussed the drop in cost of global LCOE of renewable energy in report. The renewable energy penetration in world power market has doubled in space of 9 year since 2010 to 2017 and the total renewable power generation has surplus 2000GW in 2016. The growth in renewable will continue due to deployment and cost especially in solar. The levelised cost of solar PV electricity drops by 73% between 2010 and 2017 as shown in figure 6. The LCOE from on shore wind farm is compatible with fossil fuel but that of concentrated solar and off shore are still in infancy stage. The renewable energy will be compatible with energy from fossil fuel in 2020 (IRENA, 2018).

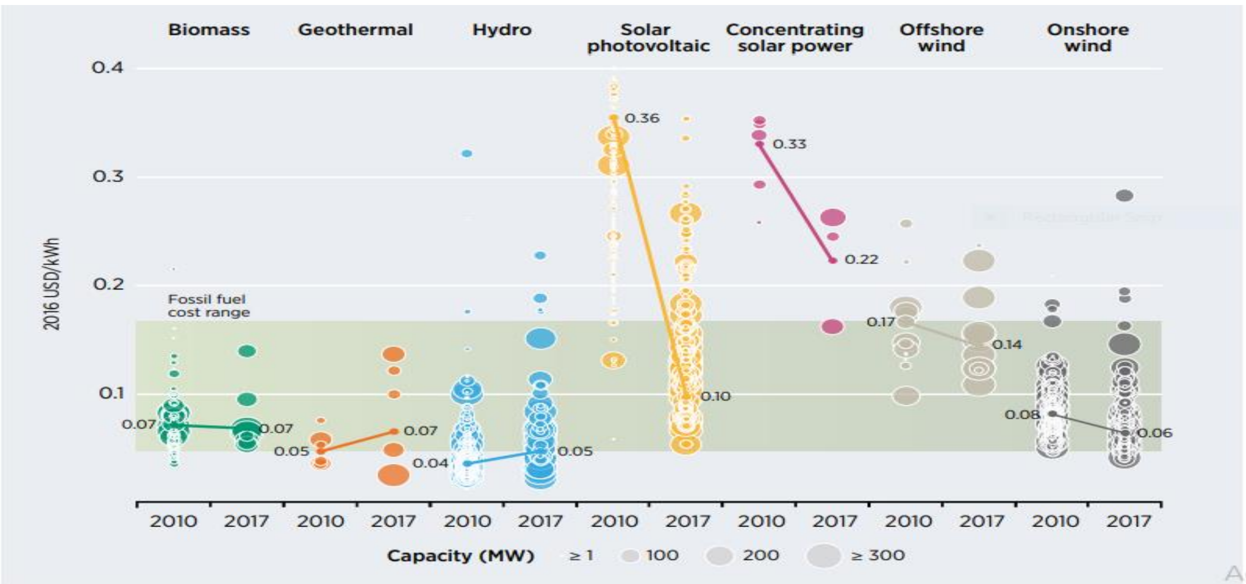

Fig: 6. Global levelised cost of electricity from utility-scale renewable power generation technologies, 2010-2017

Wichert also predicted in his research that renewable energy is the only alternative for the rural communities leaving off grid and use biomass as source of energy. He mentioned in his research that hybrid off grid will be an integral part to satisfy the remote communities in India (wichert, 1997).

Mandal and his co researchers has summarized the desire characteristic of renewable technology for rural electrification, the renewable energy technology should posses the following characteristic in order to be deployed:

- Renewable energy technology should be simple and able to provide comfortable life
- Increase the income level of communities and save the time and energy of human
- Technically and financially and viable
- Sustainable and completely comfortable

For any renewable energy technology there should be relevant skills available locally so to maintain its operation at desire level for operation (Mondal, et al., 2010).

There is an ongoing debate regarding renewable energy system, stand alone or a combination of renewable energy system or a hybrid including diesel generator, selection. Akikur et al drew a comparison between standalone renewable and hybrid energy system. Either of the system requires energy storage to work effectively. The storage must fulfill the following criteria for the system to be viable:

- Cost of storage must be low and be energy efficient
- Long useful life and low maintenance cost
- Self discharging and easy operation able

A levelised cost of energy was carried out for both system, both system produce cleaner energy, but the cost of energy for hybrid system remain steady with increasing distance from grid connection and hence more suitable for rural electrification (Akikur, et al., 2013).

Similar arguments was also raised by Wichert in his research that hybrid system reduce the total life cycle cost and increase the reliability of power supply compare to the standalone system power generation (wichert, 1997).

The advantages and disadvantages of renewable energy technologies (solar, wind and hydro) discussed by Fong. The advantage of solar energy is more than disadvantages in sense of rural electrification. But for wind and hydro energy it is very important to select ideal location for the generation enough power because of cost association with these technologies. A combination of renewable technologies could be ideal for rural electrification if location is ideal for all generation (Fong, 2014). The stand alone systems of renewable energy systems are not reliable because renewable energy sources are not intermittent so the hybrid energy system, a combination of renewable energy system, is the only ideal option (Nakata, et al., 2005). The hybrid renewable energy system was supported by Byrne and his co researcher. In their research they proposed a hybrid energy system for a remote area in china, the village for away from grid connection. The proposed hybrid energy system (solar, wind and energy storage) is an ideal solution for electrification of remote area (Byrne, et al., 1998).

An energy generation model was produced by Nakata using multiple renewable energy resources. The produced model was applied to a village in Japan for producing energy from renewable sources. The results obtained from model showed reduction in CO_2 by half and also reduction in cost of power generation. This showed that hybrid system is better option for reliable and cost effective and environmental friendly power generation (Nakata, et al., 2005).

2.2 Rural electrification benefits:

Providing power or electricity to rural communities will have numerous positive impacts. Kaygsuuz states the important of electrifications in following words:

"Universalisation of access to electricity in the world is of fundamental importance for the eradication of poverty and reduction of social inequality"

The electrification of rural communities will not only benefits them in homes but also increase their income level by increasing economic activities. The Asian countries agricultural productivity has risen because of access to electricity, increase productivity by better irrigation using water pump and mechanization and transportation and better communication. The use of renewable energy, solar water pump, meets the need of farmers in rural Africa (Kaygusuz, 2011). The renewable energy can be utilized in the following process in rural area especially in Agriculture sector:

- Solar energy dryer for drying crops
- Building small hydro plants for power generation
- Using solar water pasteurizer
- Bio gas plant for production biogas from biomass
- Fishing drying using solar dryer
- Charcoal production and beer brewing
- Reduce migration to main cities by generation local jobs

Access to modern energy will reduce the energy inconvenience in rural communities significantly (Karekezi & Kithyoma, 2002). The inconvenience associates with no power can be summarized in the following points:

- The frequency of buying and collecting fuel from cities and town for lighting houses;
- The distance to travel for collecting fuel and type of transport use to and from town to villages.
- The time consume for procurement of fuel and health issues with fuel burning;
- Collecting biomass in villages for heating and burning usually children are involved;
- Bad indoor quality and non productive consumption of time;

If energy is available for villager or remote area, they can utilize their time in best way of generating or running business and children can go to productive works like study, play and other learning activity (Mirza & Szirmai, 2010).

The burning of biomass in homes in remote areas of developing world associates with a lot of diseases especially the one related to chronic respiratory diseases like asthma and so on. These diseases can be reduced by providing modern electricity to remote area. The supply of electricity will improve the health of woman and children in villages as those are the one who are more expose to the bad air due burning of biomass at homes (Jan, et al., 2011).

2.3 Selection of software for model:

Homer (Optimize Model of Hybrid Energy Resources) developed by NREL (National Renewable Energy Lab). Homer is a community scale tool for modeling electrical energy system but expanded to model grid connected and thermal system like solar biomass system for rural area in Pakistan (Shazad, et al., 2017). A.Lyden et al suggested Homer for community scale electricity system design or off grid system for remote area (Lyden, et al., 2018). Homer also used for off grid energy system modeling by Bhattacharyya and Sen for a village in India (Sen & Bhattacharyya, 2014).

The new version of Homer software also consider the socio economic impact of power system modeling, the Homer is an excellent tool for off grid model system design but like any other software it does have limitation which need to be consider through investigation.

Lambert in his research describes the competence and basis of Homer underlying calculation (Lamber, et al., 2006). Homer utilizes Lambert equation for renewable technologies power output.

Homer also considers the COE or LCOE, an additional advantage of Homer; provide the financial viability of system for communities to adopt.

The Homer utilize NPC (net present cost), life cycle cost of the system and it basis for the financial viability of the system or can offer the lowest NPC from available renewable energy technologies (Lamber, et al., 2006).

3. Microgrids:

Several definitions for Microgrid are available I literature but the most broadly one is as follow:

“An energy system which consists of distributed energy sources (storage and generation) and loads. These energy systems can operate independently of the grid and synchronous with the grid providing them with full flexibility and control (level, 2016)”.

Microgrid mainly consists of power generation units, distribution network, voltage regulation and gear or switch. The Microgrid differ from normal grid in sense of it location. Microgrid is build close to consumer compare to the traditional grid which are miles and miles away usually from consumption area. Due to its closeness to consumer or customer distribution losses are minimum and its healing characteristic make it different (level, 2016).

The advantages of Microgrid it maintain reliable and uninterrupted supply of electricity to consumers, so it increase security of supply, due to its ability to act dynamically. It has high renewable penetration compare to traditional national grid where power comes from burning fossil fuel (Gao, 2015).

3.1 Energy storage in off grid energy supply system:

As off grid energy supply use renewable sources of energy and renewable energy sources are intermittent due to its nature, energy or electric supply can be disturb or interrupt. To sustain a constant supply of power to consumers an energy storage requires in the system. Several different storage systems are available which can be added to system such as batteries, flywheels, pump hydro and super capacitors.

3.2 Selection of storage in rural perspective:

Several storage technologies are available but the one with small volume in high energy density is favorable due to space, reliability and capacity. The battery and fuel cell are the one with small volume but the energy density of fuel cell is less compare to the battery (system, 2015). For most of the off grid energy system Surrette battery is selected due to long life and durability and reliability (Sen & Bhattacharyya, 2014).

4. Pakistan and its Power Generation:

Pakistan is in South Asia and one of the world most populated country or sixth largest country with respect to the population in world. The current population is 207 million with a growth rate of 2.4% annually (Bank, 2018). Pakistan is predominantly

Agriculture country and 62% of its population are living in country side or in rural area. (Bank, 2016). The country is divided in to four provinces and Northern area and Azad Kashmir. Khyber Pukhtoon Khwa which in North West of the country and is one of the Mountain province and most of the mineral comes from this province. The village selected is in District Mohmand previously known Mohmand Agency. Mohmand Agency was part of FATA (Federal Administrated Tribal Area). The approximate location of the village is shown in Figure 8 with arrow to the location and a Google earth shot show a close location of the village.

Pakistan political instability with no clear energy policy in past have put pressure on already existing infrastructure of generation and distribution of electricity. Pakistan installs capacity of 23000 MW but can hardly generate 17000 MW power with a shortage of 5000 to 6000 MW. The shortage in power meets by load shedding. People living in cities is still facing few hour of load shedding while those in rural area have hardly two to three hour of power if grid connected (Amin & et, 2014)

Historic Demand Supply Position

Fiscal Year	Computed Peak Demand	Corresponding Supply	Surplus/ Shortfall
2001-02	10459	10894	435
2005-06	13847	12600	-1247
2010-11	19230	13163	-5581
2013	20016	16100	**3916**

Table: 7

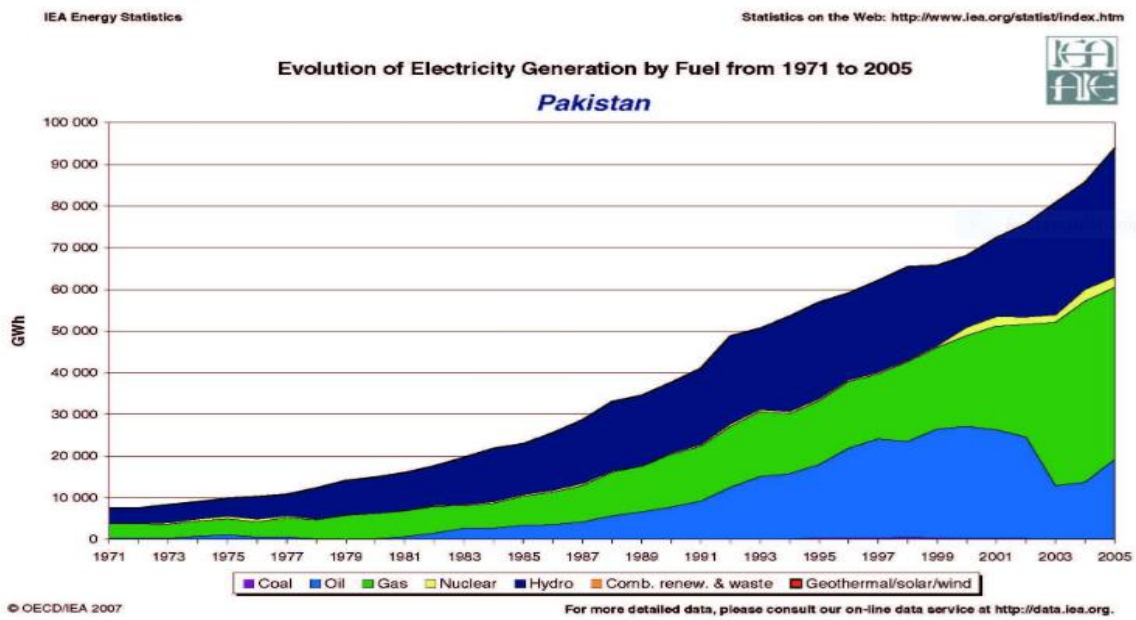

Figure: 7

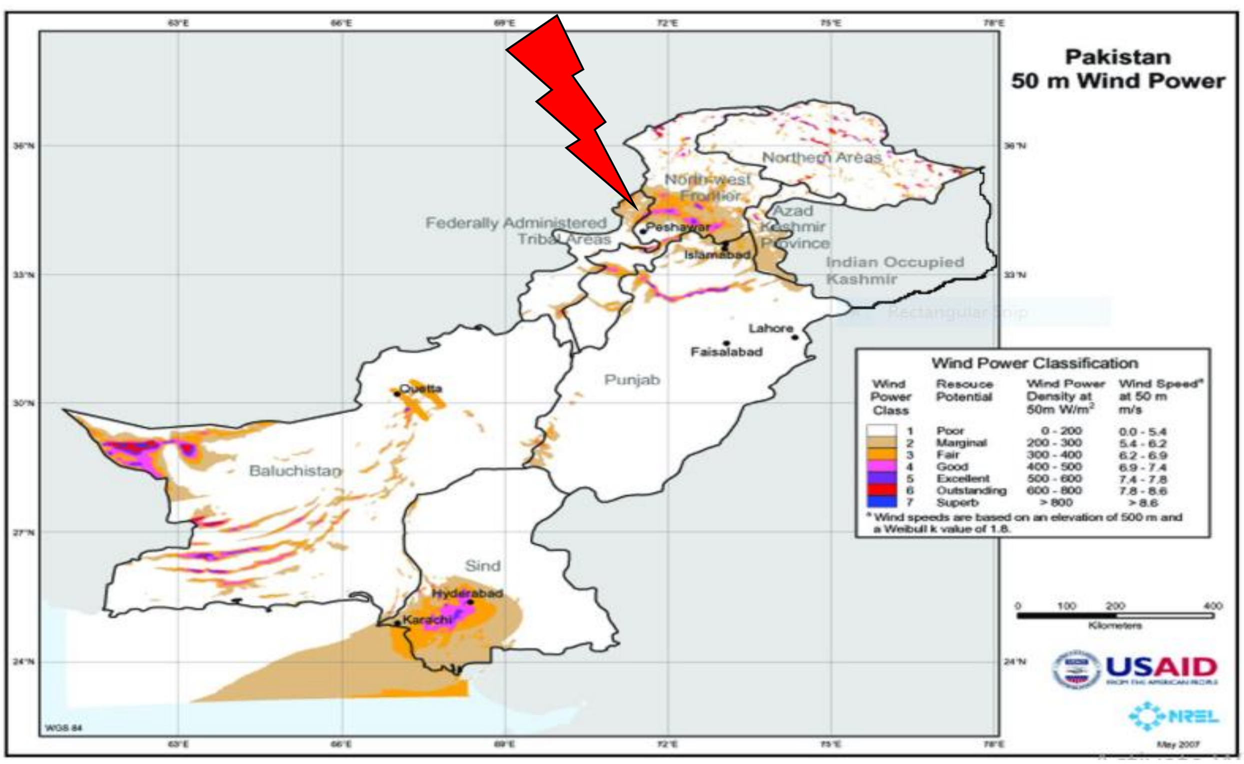

Figure:8

From the figure 7, it shows that up 2005 the major constitut of energy supply to the country's was oil, gas and hydro. The Nuclear starts since 2000 and expand with time due to future plan for nuclear energy generation. The demand for power demand increaase with time and this demand will increase the emission of Green House Emission to the enviroment. The fossil fuel will diminish with rise in demand due to the limited reserve of fossil fuel. The fossil fuel limition will results in energy security of supply. The results will be in the form of more loadshedding or blackout and will also decrease the industrial production and more jobs lossses and losses of ecnomic activities. The penetration of renewable energy in national grid or supply of to rural area of country will decrease the pressure on national grid and will decrease the production of energy from fossil fuel results in the clean enviroment.

The selected village for this study is located off grid and terain is hilly. The grid extension to that area is not a plan in near future due to the number of reasons, village is far away from National grid and the grid is already under tension due to lack of supply to already grid connected resident. The slected District was prviously known as Mohamand Agency and was administrated from Central governament, no local government structure was present.

Offgrid energy solution is the best option and will investigate the possibility of energy supply from renewable resources with minimum cost of energy and investment.

4.1 Khyber Pukhtoon Khwa (K.P.K) District Mohmand Village Soran Mitti:

For any renewable energy system design it is important to ivestigate the climate data of the selected area because to find out suitable renewable energy technology could be utilise in the system. Additionally the climate data will validate the use of respective renewable technology in the energy system model. The resources analysed were wind, solar, biomass and hydro.

Figure:10: Distric Mohmand

4.2 Wind Speed:

According to NREL (National Renewable Energy Labotary) of United state that Pakistan has the potential of 346 GW of wind energy approximately. As shown in the figure 11 below the wind speed in the costal zone of Sindh province and of Balochistan. The wind speed of sindh costal area is approximately 5-12m/s. similarlry can see in figure 11 below the northwest of the country also have the poetential of wind energy (Baloch, 2017)

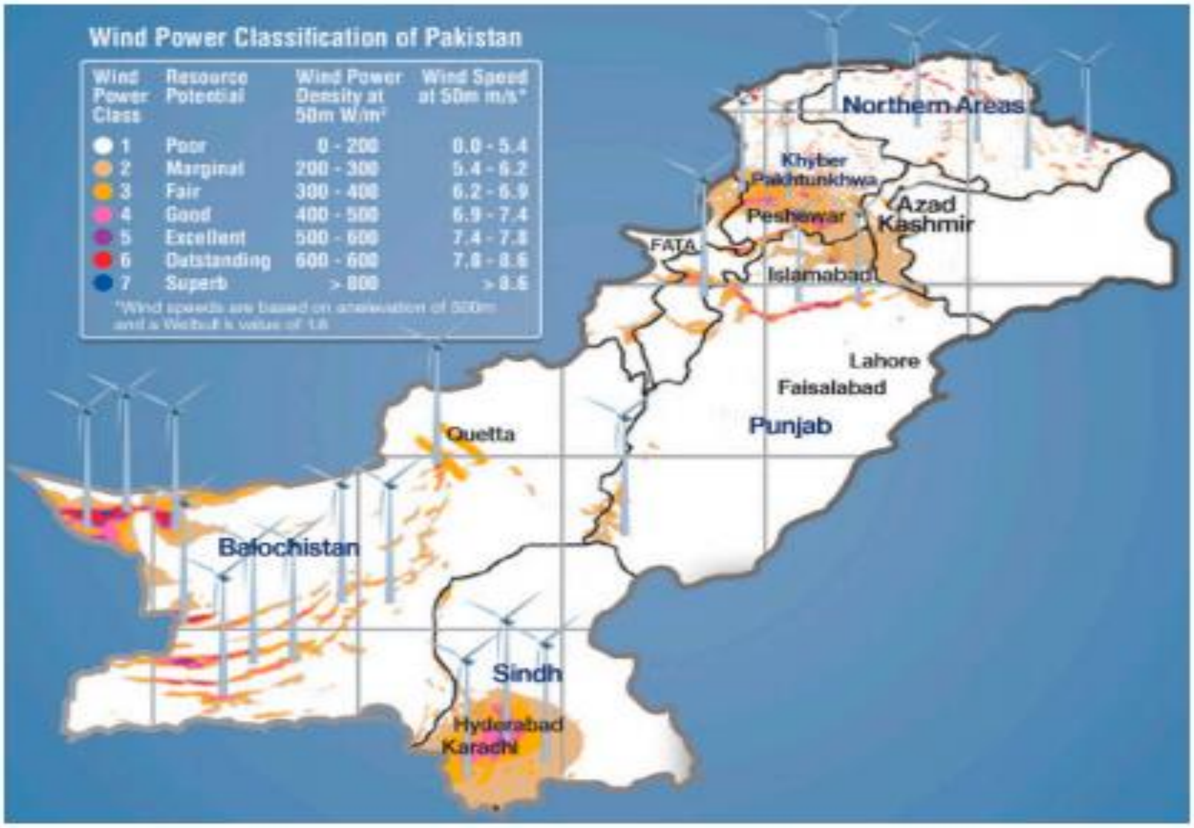

Figure:11: Pakistan wind speed map

Average wind speed was downloaded from Nasa wind speed data for Mohmand Agency because of the absence of local weather station.

Figure: 12: wind speed map of North West of Pakistan

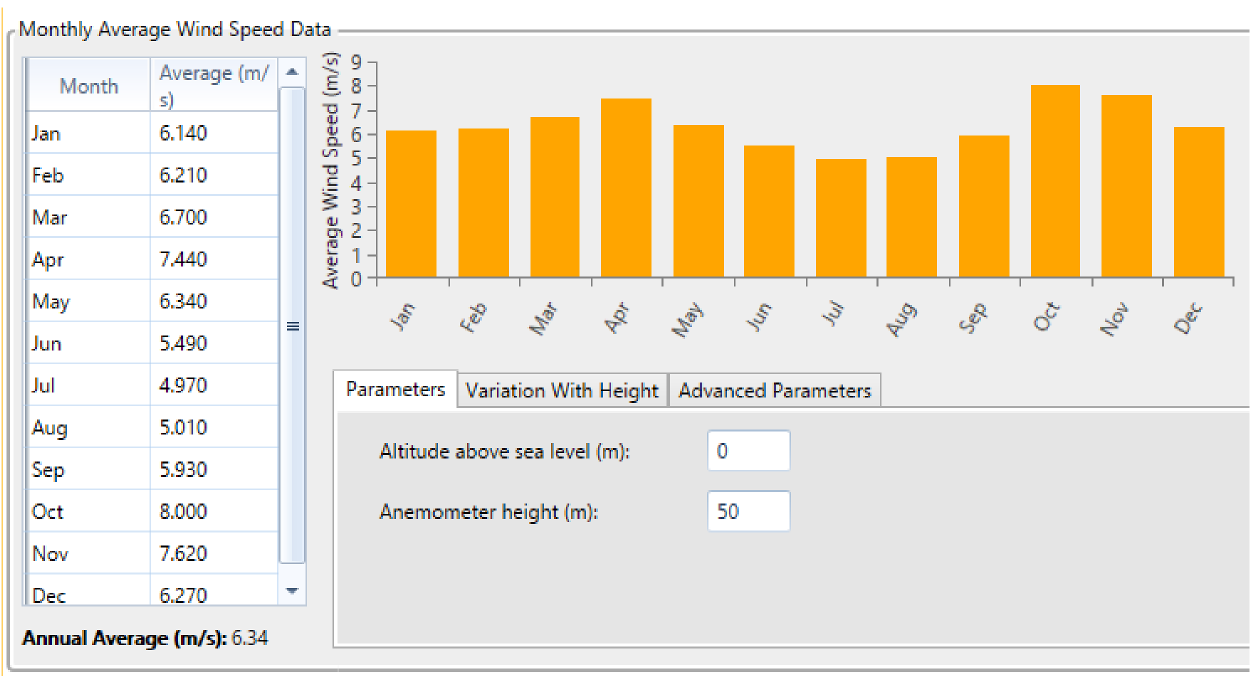

Figure:13; Monthly average wind speed of the village Soran (District Mohmand)

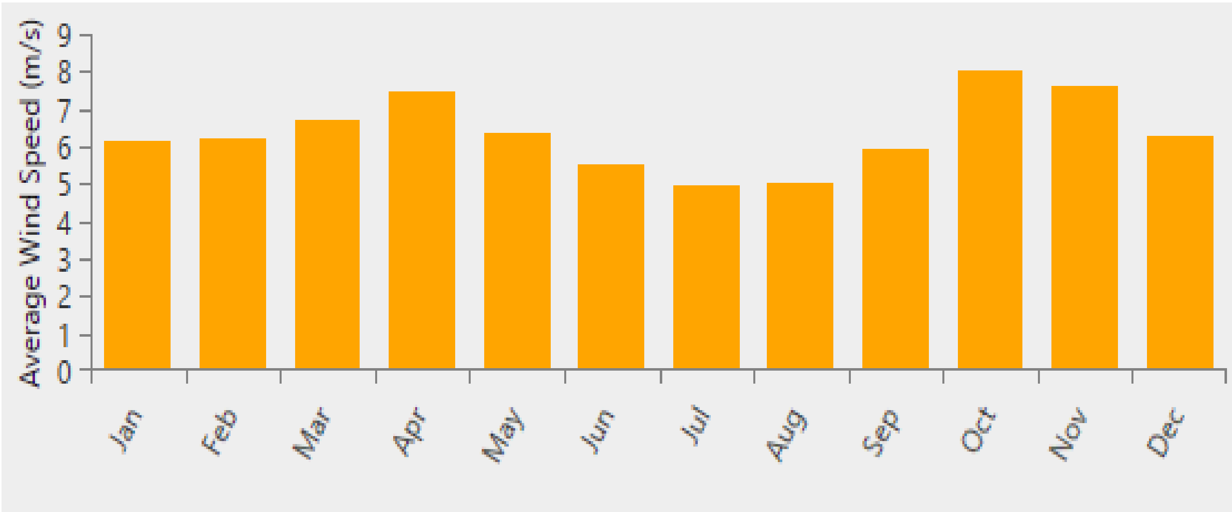

Figure:14 Monthly average wind speed of the village Soran (District Mohmand)

The figure 13 and 14 shows the average wind speed of 6m/s which is the average speed for a wind power generation in that locality. As the figure 14 show the highest average wind speed is 8m/s while the lowest is 5m/s. the highest and lowest average wind speed is the validation of using wind turbine in model for power generation.

4.3 Solar resources of village Soran District Mohmand K.P.K Pakistan

Pakistan is located in South Asia at a latitude of 30.3753^0 and at longitude of 69.3451^0 . It has immense solar resources that is well suitable for photovoltaic and as well for concentration solar power application all over the country over year around. The direct solar radiation for the selected location, District Mohmand Village Soranan at latitude and langitude 34.5356° N, 71.2874° E, is 4.5 to 5 $kWh/m^2/day$. Similarly global horizntal and flat plat which can be used for photo voltaic power application.Due to dryness in winter season less solar radiation occur compare to the summer in which the highest solar radiation occur. The solar radiation in spring and autum are of intermediate leve. From figure 15 shows the annual average solar radiation for the selected locality is 5 $KWh/m^2/day$. This is enough to generate enough energy for the local papulation.

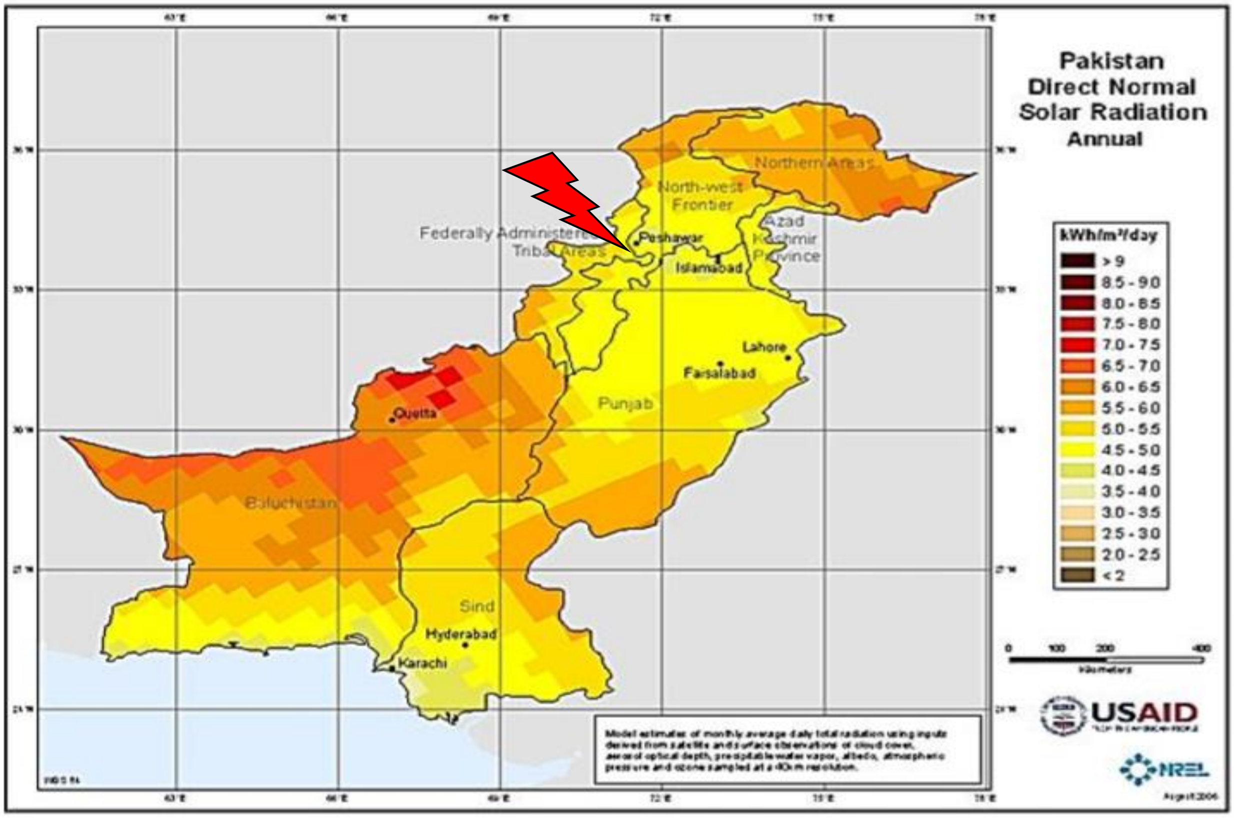

Figure:15 Direct solar radiation of Pakistan

Annual Flat Plate Tilted at Latitude Solar Radiation KWh\m²\Day map

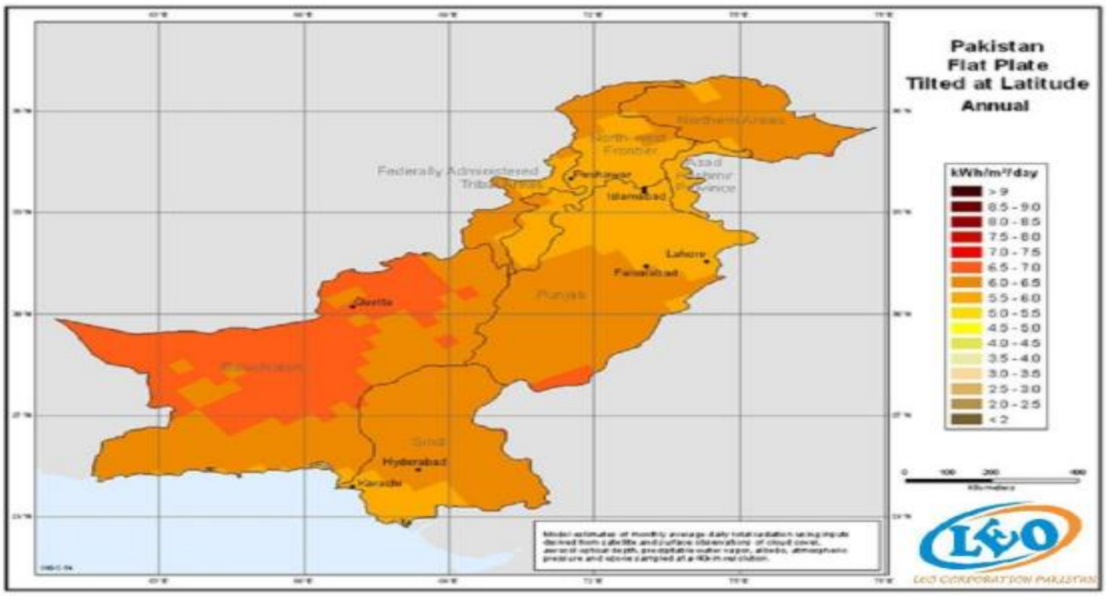

Figure:16; Pakistan solar flat plate solar map

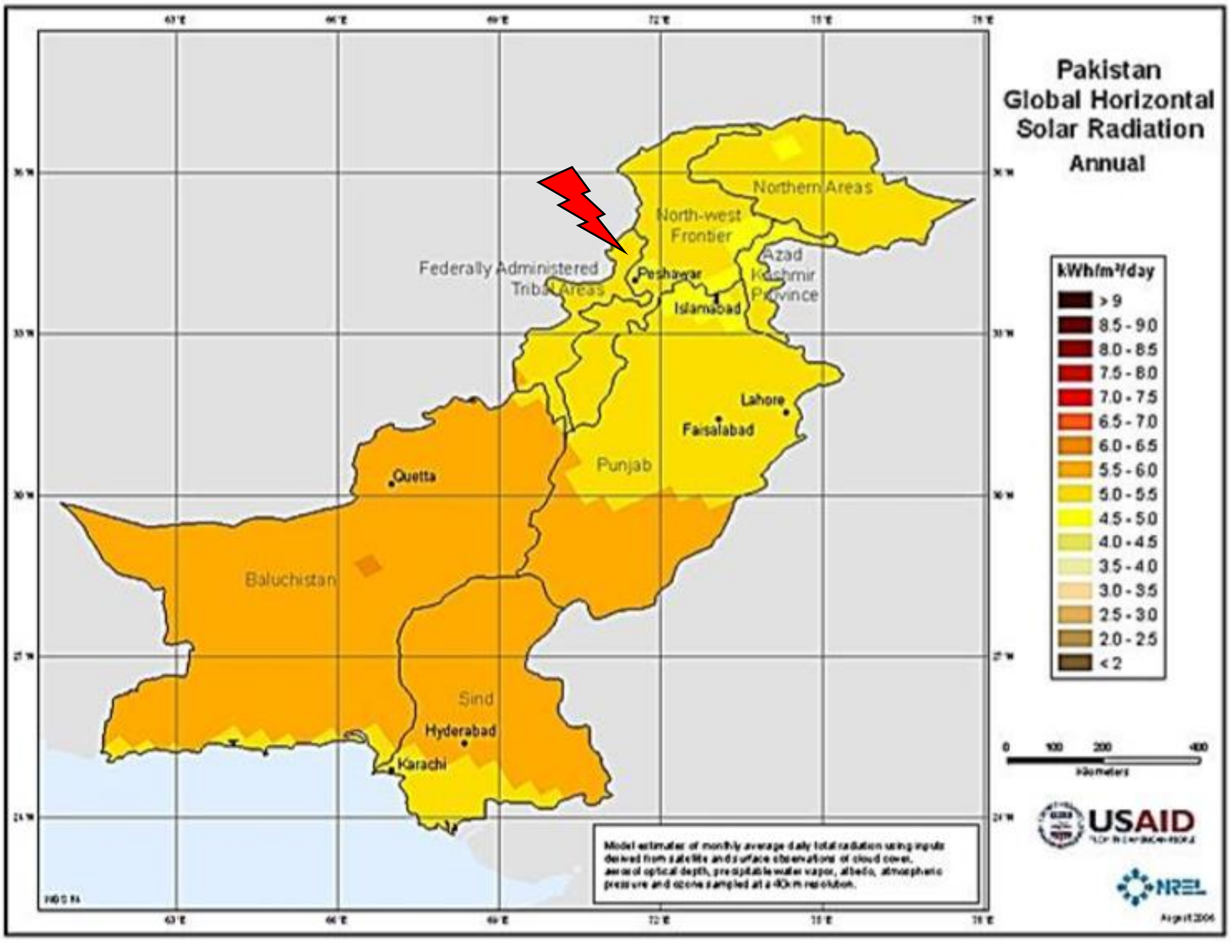

Figure:17; Global Horizntal Solar radiation Map of Pakistan

4.4 Hydro resources of the village for renewable energy production:

A significant hydropower potential is present in Pakistan. Govt deployed a number a number of project but the development of the project is still not completed because of the financial problems and high initial capital cost of dam construction. The total install capacity of hydro dam for power production was 6720 MW upto 2010. The total poetential of hyropower in Pakistan is up to 60000 MW, only 11% of the total potential is utilised up to now. Almost all the hydro potential and developed dam are I K.P.K (Khber Pukhtoon Khwa) previously know as North West Frontier Province the figure 18 indcate the develop and under develop location in the province. The indus river basin which start from North of the country and end at south into sea, contain 75% of the total hydro potential. The selected location (Soran District Mohmand) is almost on Afganistan and no near by river is present in the area. The hydro power is not consider here.

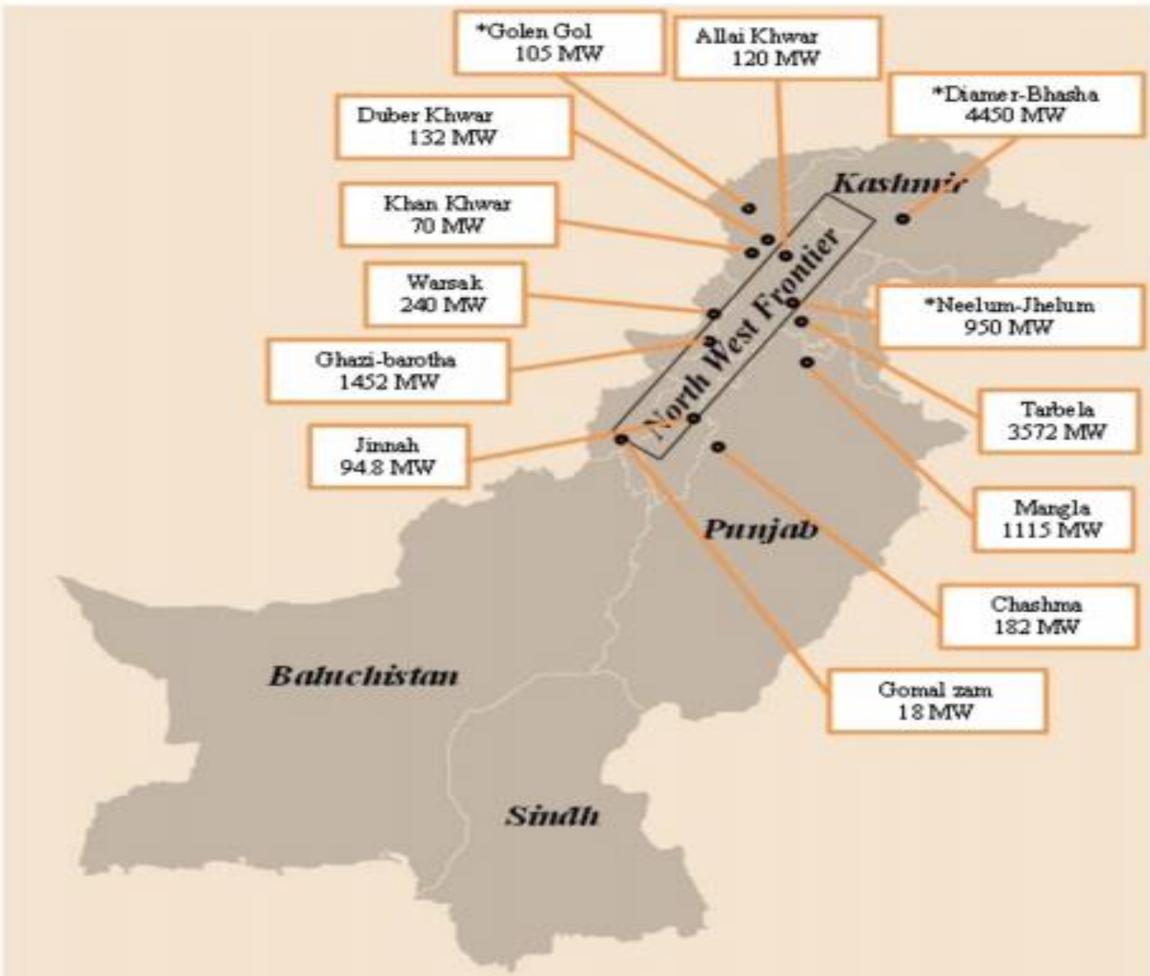

Figure:18 Pakistan Hydro Dam location map

4.5 Biomass resources of the location:

Biomass can be used for power production and is an excellent source in respect of green technology. As mentioned earlier the selected area or village is a remote and hilly the biomass resources is very limited. The biomass or agriculture waste is mostly in south of the country as can see from figure 19 the green section of the figure show biomass or agriculture waste generation area of the country. So biomass utilization in energy system production for the locality is not considered.

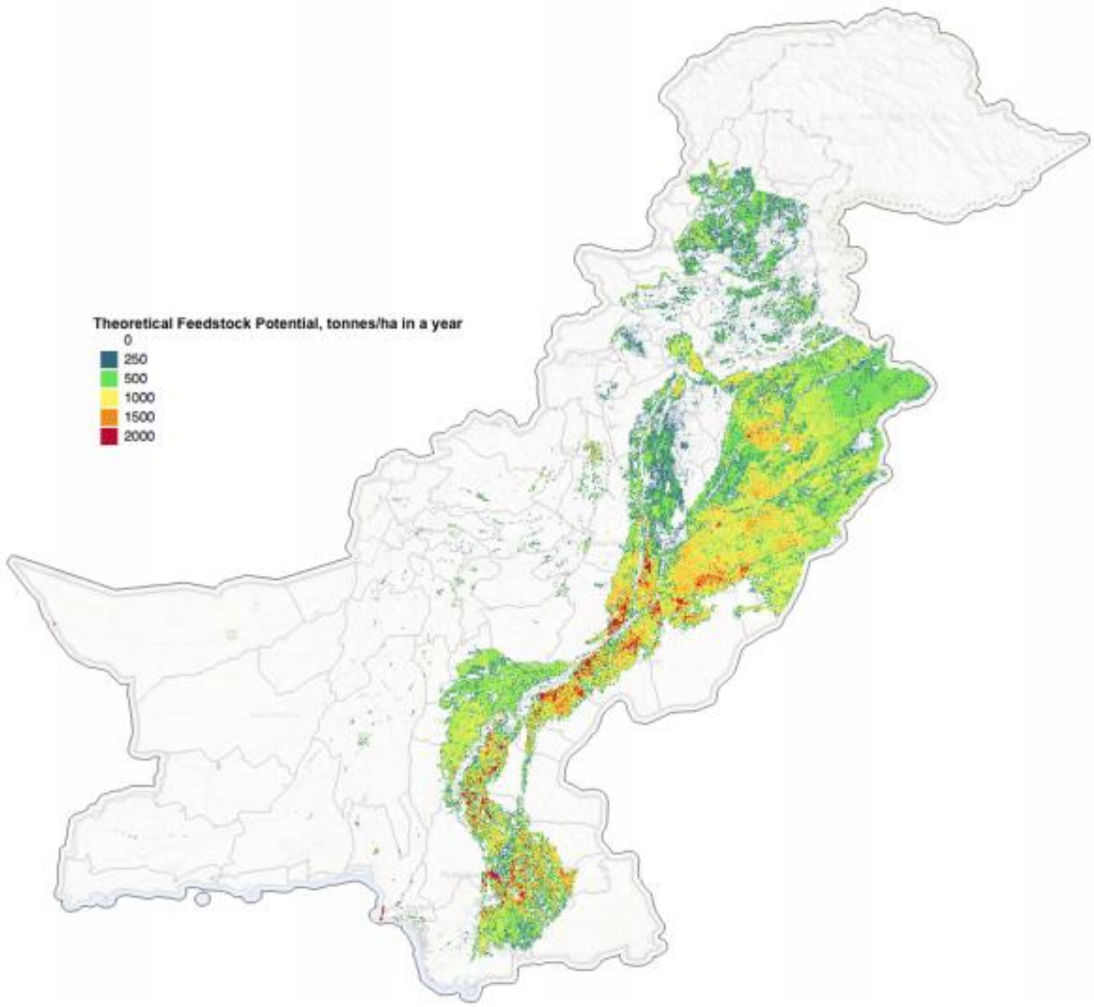

Figure:19; the biomass abundance area of Pakistan

5. Demand survey of the village:

The information regarding village energy consumption is not available due to remote area and no connection to national grid or any sort of power supply. A survey must be conducted in order to get the necessary data for energy consumption in future if power available.

As no power is available in the village to estimate the demand profile, survey was carried out in another village of the same district.

The survey was conducted with the aim of collecting information for the possible electricity consumption pattern in the village. The survey focused on, types of housing, lighting demand, water demand, demand of power for use of fan in summer, School power demand, medical centre power demand and mosque. The results from survey were used to identify the electric consumption pattern and the estimated the demand profile for the village.

Survey sheet for the village

For each question, a selection of answers is provided on right hand side. Please tick an appropriate answer for each question.

Table 1: Housing

Questions	Answers
What type of house do you live in?	Rural Urban Modern
What materials are used in the structure?	Brick Stone Cement Mud Stone
Do you have street lights?	Yes No
What is your income level?	Poor Intermediate Rich

Table:2 Fan (Ceiling & Pedestal) & Iron

Questions	Answers
Do you have a Fan (Ceiling, Pedestal) in your house?	Yes No

If yes, how frequently do you put it on?	Daily Few Days Weekly Fortnightly
How many hours at a time do you use it for?	2-4 hrs 4-6 hrs 6-8 hrs 8+ hrs
Do you have Iron at your home?	Yes No

Table:3 Lighting & radio

Questions	Answers
What do you use for lighting in your home?	Light bulbs kerosene lamps
If light bulbs, what type of light bulbs do you use?	Incandescent Halogen CFLs LED
Do you have Radio at home and what time do you switch on?	2-4 hrs 4-6 hrs 6-8 hrs

Table:5 Fridges &washing machine and water pumps

Questions	Answers
Do you have Fridge at home?	Yes No
Do you have washing machine at home?	Yes No
Do you have water pumps at home?	Yes No
Do you have well water pump at village?	Yes No

Table:6 Mosque, shops and Medical centre

Questions	Answers
Do you have shops in village?	Yes No
Do you have mosque in village?	Yes No
Do you have Medical centre in Village	Yes No

The village in the same district survey helped to estimate power requirement and consumption pattern for the village Soran District Mohmand K.P.K in future if power is supplied.

5.1 Types of houses and income level of household:

The people living in the village are blood relative and the income difference is not that much because of extend family members. The houses are made of mud and stone but in future if power is supplied to the village will change not only the housing style but also increase the income level and create local jobs.

5.2 Types of lights:

the lights available in the local markets are mostly low energy lights and people prefer to use low energy lights due to the units consumption bands for domestic home, those use more power are charge with higher rate per unit compare to those use less units, because of government subsidy for low income homes.

5.3 Fans:

The entire resident of the village does have fans, ceiling and pedestal fan, and switch on in summer, afternoon and night. There is no heating and cooling system inside homes because of the house structure. All of the homes are made of mud and stones; remain cooler in summer and hotter in winter.

The electrical appliances are used by the local resident in the village which would aid to determine the final energy consumption pattern.

The following table; shows the appliances appeared in survey and their usage time as well.

Table:7

Fridge	24 hour a day
Low energy light	10 hour a day
Washing machine	2 hour a day
iron	2 hour a day
radio	3 hour a day
Ceiling fan	14 hour a day
Pedestal fan	14 hour a day

shops	9 hour a day
Mosque	5 hour a day
Water pump	4 hour a day
Medical centre	8 hour a day
well	4 hour a day
School	6 hour a day

The possible improvements in future:

- The power consumption can be increased in future in houses with introduction of more appliances with rise in income level if power is supplied
- All cooking option in future could be replaced with electric appliances. This will reduce the consumption of LPG in houses and ultimately will reduce the green house emission.

The survey was conducted in a village with access to electricity in same district. The survey provide a basic power need for daily life in that culture and can consider similar demand in the village of Soran. The sample provides a basic power demand which can be utilized for modeling section but this will not provide a complete picture for power consumption but will use as estimate for the investigation.

6. Software selection criteria;

A numbers of software options were available for the investigation of power supply from renewable source, but the selection of Homer optimizer was best option due to the homer focus on Microgrid system design. The homer software is able to run a number of simulations of various renewable technology combinations simultaneously.

Secondly the Homer software simplifies the renewable energy system design for rural or developing countries by downloading solar and wind data from a respective source (NASA metrological surface data).

Homer had added optimizer to calculate the technical and financial viability of a renewable technology combination. Similarly the sensivity analysis is also added, changing one or more variable on hybrid Microgrid system, which reflects on the system result.

The software selection was followed by the validation of the software to ensure the output of the design model is correct and meet the criteria.

Model Validation for Soran

The Homer model validation is very important before using it to design a sustainable energy system for the village or off grid communities, to ensure the model function properly and produce realistic results. In order to validate model, the demand profile of village Soran District Mohamnad was used with a scaled peak average of 264.12kwh/day for 10 household in order to represent with same characteristic as shown in table 11 of chapter 7.

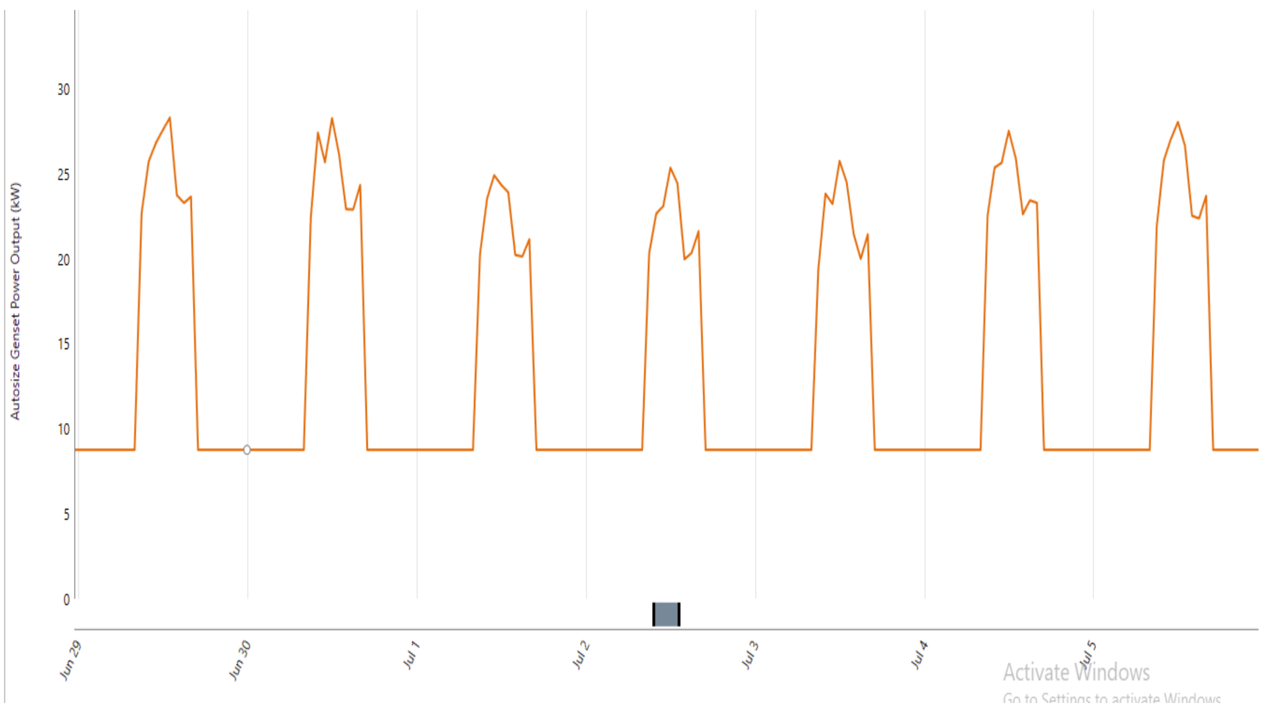

Figure 20 - 1 week demand with an auto-size generator (of 35 kW)

To validate the model a diesel generator was added to model and simulated for the village load. As shown in figure 20, generator is producing enough power to meet the require demand of the village. This shows that the system will work if only diesel generator is supply to local area for power production.

Next added solar PV (photo voltaic) and downloaded solar resources from NASA surface metrology and solar energy database (NASA, 2019). The figure 21 shows that the PV power output power is sufficient to meet the demand at day time but is insufficient at night because of no solar light.

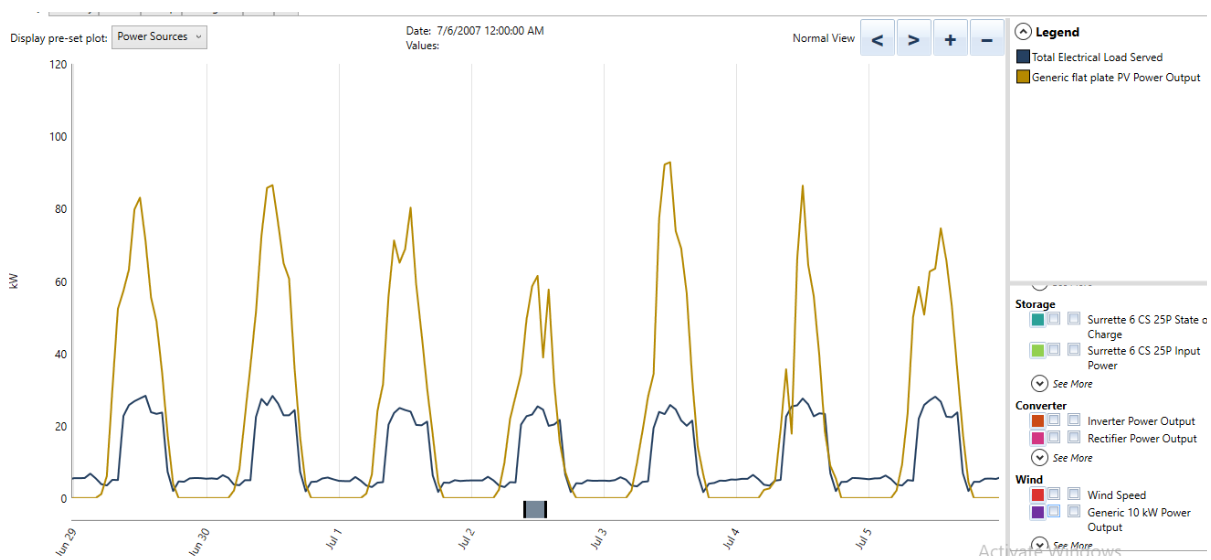

Figure 21- 1 week demand with 112kW PV array

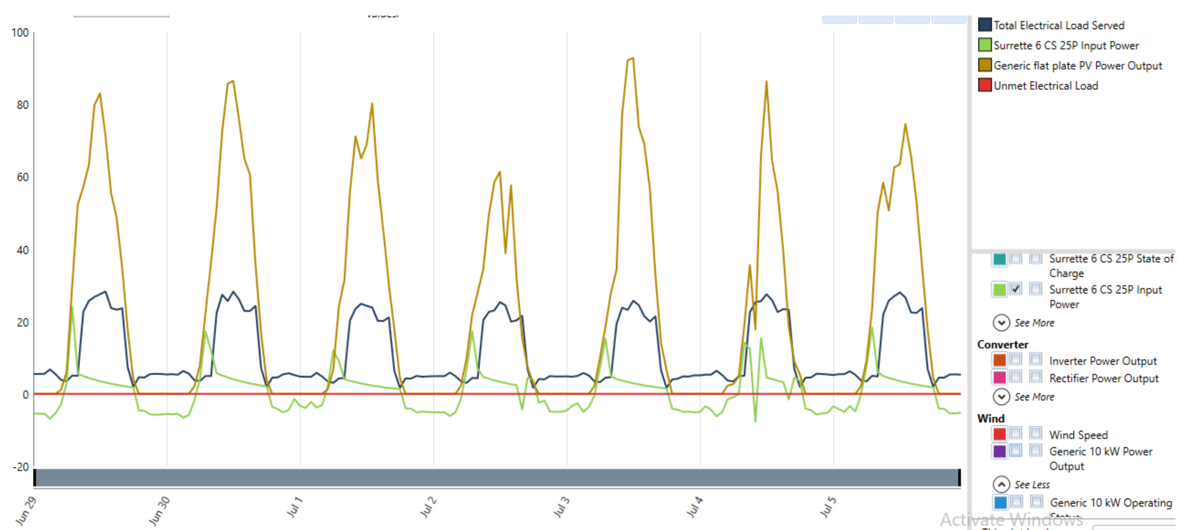

Figure 22 - 1 week demand with PV array and Battery storage

The next step was to add storage to the system. A storage battery Surrette 6CS25P was added to the system but still the system was not performing according to the desire results as shown in figure 22.

The next step was to add a Wind turbine and the wind data was downloaded from NASA surface metrology (NASA, 2019). The surplus energy from PV was store in storage and use at time when the demand is very low along with the power generation from wind turbine. The system simulation shows that it satisfies the power requirements of the village without interruption as shown in figure 23.

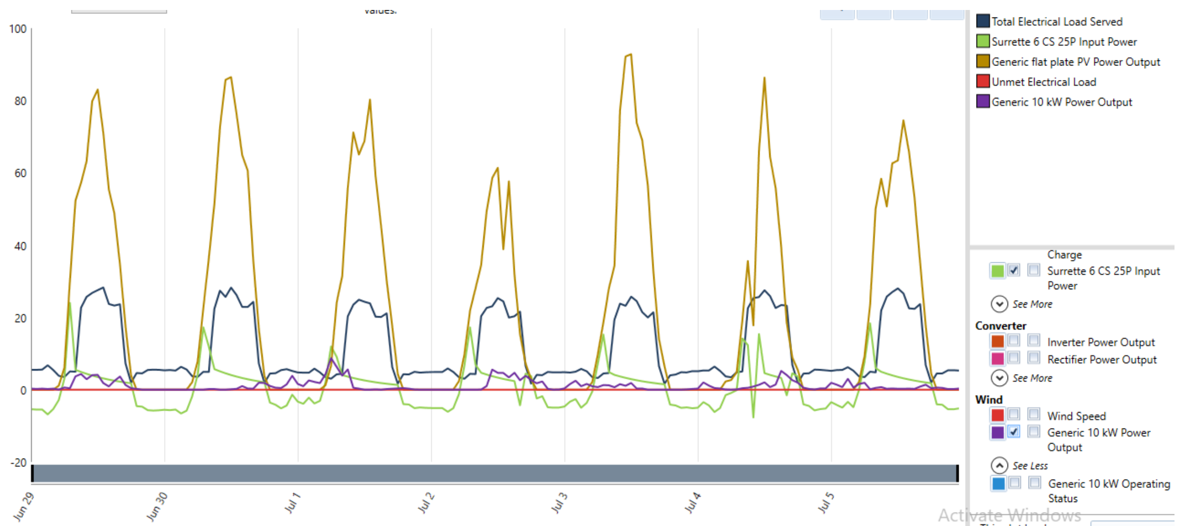

Figure 23- 1 week demand with PV and storage and wind turbine.

The design model, overall, works perfectly as expected and the results shows from the design model of a Microgrid. So, the investigation for the model completed after the validation of the model.

7. Modeling and Simulation

Due to vast, remote and hilly area of District Mohmand previously known as Mohmand agency, a small village near Afghanistan boundary was selected as a case study. No detail was available regarding the village, so it was assumed that village composed of 10 household.

The following aspects need to be considered in order to complete the modeling.

- Demand profile of the village for power;
- Solar PV resources of the area;
- Wind resources (wind speed);
- Diesel generation possibilities;
- Power storage facility

Table: 8: Scenarios definition or scenario combinations

Scenario: 1	PV	Generator and storage	present
Scenario: 2	PV	Generator and storage	Future
Scenario: 3 (Present)	PV	Wind turbine	storage
Scenario: 4	PV	Wind	Generator and storage

The simulations were run for different scenarios as shown in table:8

- Scenario: 1 utilized generator at present price (2019) of diesel and renewable:
- Scenario: 2 utilized generator at future price (2029) of diesel and renewable:
- Scenario: 3 utilized PV, wind turbine and storage (battery) and generator(2019):
- Scenario: 4 utilized PV, wind turbine, Generator and storage future:

The four scenarios were selected to observe the results of certain changing variables on the design system for the village power supply.

As the scenario, 1 is based on the present financial situation with respect to diesel and renewable technologies. However the financial scenario changes with time, the energy supply design may not be financially viable in future as it is viable at present. The cost of the fossil fuel has gone up in last decade and the cost of renewable technologies has drop quite substantially. As a results of the above mentioned reasons the scenario: 2 was design to predict the financial changes on the power supply to the village if it happen.

Scenario: 3, in this scenario all the renewable technology were used at the present cost and system was investigated financially and its future perfective with reduction in cost.

7.1 Future cost of renewable technologies (Solar and Wind turbine and diesel):

The cost curve or the trend in the price change of renewable technologies is shown in figure 2, 3, 4 and 5. All figures show a reduction in cost of renewable technologies. Most of the trend percentage is calculated on base of ten year period or five year period. To be consistent with trend let consider the same period of change, means 2029 will be a percentage change year. So solar has decrease of 58.3% and wind has drop to 61.5%.in cost. On other hand the diesel and other fossil fuel prices has gone up 40-50% in last ten year in Pakistan. This rise in fossil fuel will rise in future because the fossil fuel reserve are depleting dramatically in the world.

Table: 9 percentage changes in price for scenario, 2 and 3.

Fuel/Technology	% changes in fuel/Technology
Diesel	**+40%**
Solar	**-58.3%**
Wind	**-61.5%**

The demand profile was estimated for the village and the solar resources and wind speed were downloaded from NASA surface metrology (NASA, 2019).

7.2 The demand profile of the village or electric power demand:

For Homer simulation it is necessary to determine the load profile for respective simulation. The demand profile was estimated on the basis of survey information from nearby village, not exactly in the same area but in same district. The appliances and their hour of usage are shown in the table 10 below.

Appliances	No: in Use	Power in Watt	total Watt	Summer hour usage	Kilo Watt	KWh
Fridges	10	180	1800	24	1.8	43.2
Low energy light	30	20	600	10	0.6	6
low energy light	30	20	600	10	0.6	6
Low energy light	30	11	330	10	0.33	3.3
Washing Machine	1	500	500	2	0.5	1
Iron	1	1000	1000	2	1	2
Radio	10	10	100	3	0.01	0.03
Ceiling Fan	30	30	900	14	0.9	12.6
Pedestal Fan	30	30	900	14	0.9	12.6
Shops	10	500	5000	9	5	45
Mosque	1	1000	1000	5	1	5
Water pump	4	745.6	2982.4	4	2.9824	11.929
Medical Centre	1	13040	13040	8	13.04	104.32
Well	1	745.6	745.6	4	0.7456	2.9824
School	1	1360	1360	6	1.36	8.16
Total		19192.2	30858		30.768	264.122

The tables 10 above show the typical demand for a small village and some assumption were made, each household consist of five members and will use such an equipment if power is supplied in future. There is no power in that locality.

Table 11 load characteristic

Metric	baseline	Scaled
Average kwh/day	257.18	264.12
Average kW	10.72	11.01
Peak	35.16	36.11
Load factor	0.3	0.3

A 24hourly demand data was entered into Homer software for both winter and summer period. The type of load selected an AC (alternating current). The local people in that locality mostly get up early in the morning and perform their daily work at day time mostly farming or other sort of work and spend evening at home or in mosque during pray time. The local community is very conservative and only listens radio for information or for news.

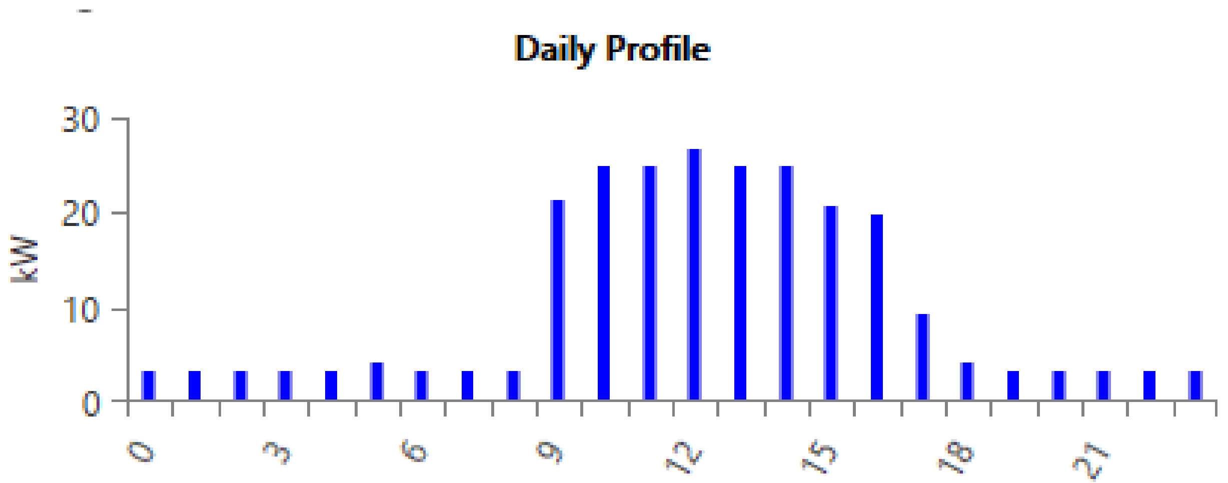

Figure 24 daily hourly load profiles

The next step was to consider renewable energy sources to meet the daily power demand.

7.3 Solar resources (PV)

Pakistan has high solar resources and the sunshine for about 10 hour a day in summer and eight hours in winter. The homer software has many options for solar panel means different types of solar panel are available in catalogue. From NASA surface metrology and solar energy database the clearness index and monthly average radiation was taken (NASA, 2019).

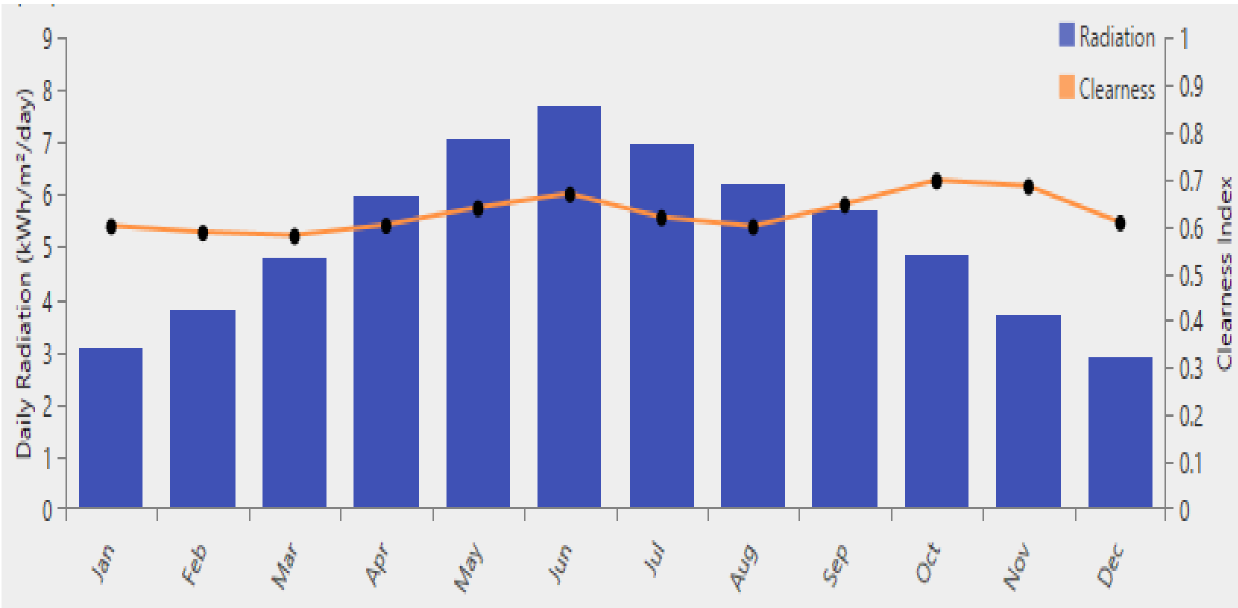

Figure 25 Solar GHI Resources Homer

Generic plate PV was selected for Homer simulation with the characteristic shown in the table 12. The future cost for solar PV is calculated on the percentage reduction in last ten year and hope will keep decrease because of more investment and research and development. The reduction in cost of solar technology is continuing since 1970 and hope will keep the same pattern in future as well.

Table: 12

Characteristic	Present cost	Future cost
Capacity of solar panel (kW)	1	1
Capital Cost of Solar Panel ($)	625	365
Replacement cost of Solar panel($)	500	292
O&M ($)	10	4.16
Average Panel Efficiency (%)	16	16

7.4 Wind resources:

The generic wind turbine was selected due to its stability. The generic wind turbine characteristic is shown in table 13 below. The future cost of the wind turbine was calculated on the percentage drop in cost of wind turbine in last ten year trend.

Table: 13: Characteristic of Generic wind turbine

Characteristic	Present cost	Future cost
Rated Capacity of Generic (kW)	10	10
Capital cost ($)	10,000	6100
Replacement ($)	8000	4880
O&M Costs ($)	500	305

Maximum power	10kW
Rated voltage	96/120/220/360V
Start up wind speed	2.5m/s
Rated wind speed	11m/s
Survival wind speed	45m/s
Top net weight	400kg
Wheel diameter	7.8m
Blades number	3
Blades material	Reinforced glass fiber
Generator	Three phase permanent magnet ac generator
Magnetic steel	NdFeB
Generator case	Die-casting aluminum
Control system	Electromagnet/ wind wheel yaw
Speed regulation	Automatically adjust windward
Working temperature	-40 to 80℃
Lubrication	Grease injection
Design life	20 years
Certifications	CE, ISO14001, ISO 9001

Table 14: 10kW generic wind turbine specification:

Source: https://www.globalsources.com/gsol/I/Windturbine/p/sm/1167688922.htm#1167688922.

In Homer software a number of wind turbine are available, the selection of 10KW was based on the option that some of the power will generate from wind and rest will come from storage. The power demand is low at night compare to day. The 10KW generic wind turbine specification regarding is shown in the table above 13.

The wind speed data was downloaded from NASA surface metrology and solar database (NASA, 2019). The average wind speed is lower in July and August but the rest of the year the speed is pretty average for wind power.

Table: 14 Monthly Average Wind Speed

Month	Average (m/s)
Jan	**6.140**
Feb	**6.210**
Mar	**6.700**
Apr	**7.440**
May	**6.340**
Jun	**5.490**
Jul	**4.970**
Aug	**5.010**
Sep	**5.930**
Oct	**8.000**
Nov	**7.620**
Dec	**6.270**

7.5 Diesel generator:

Diesel generator was added as a backup for the supply system in case of blackout or the renewable energy is not enough for the demand. The smallest possible generator should be added to reduce the cost of the system and provide stability to the system.

A diesel generator was added to the system to the system and the characteristic of diesel generator and fuel prices are shown in the table 15. The fuel price has gone up constantly and the cost of the renewable technology dropped since 1970 and the reduction in the cost is continued. The emphasis was to penetrate renewable technology instead of diesel or reduce reliance on fossil fuel. The characteristic of the diesel generator and fuel are in table: 15.

Table 15- Diesel Generator Characteristics and fuel cost

Characteristic of Generator	Value
Capacity of Generator (kW)	1
Capital cost of Generator($)	500
Replacement Cost of the Generator($)	500
O&M cost of Generator($)	0.03
Fuel Cost Present ($/L)	1
Future Fuel Cost ($/L)	1.27

7.6 Surrette 6CS25P Battery (storage)

Storage (batteries) was used as a backup for the energy supply system and to maintain a constant supply and store the extra generation at time not in use. The renewable energy is intermittent means not reliable. Surrette 6CS25P was selected for the energy supply system. It is a six volt battery with a capacity of 1156Ah. The characteristic of the Surrette 6CS25P is given in table 16below.

Table 16 - Surrette 6CS25P Characteristics

Characteristic	Value
Quantity	1
Capital cost	1000
Replacement cost	800
O&M ($)	10
Nominal Capacity (kWh)	6.94

7.7 Scenarios:

The Homer software uses optimizer to find the optimum combination from available renewable and nonrenewable resources and variable for the supply of power to the remote or off grid community or for designing Microgrid. A summary of the different scenarios was discussed in table 8. These will be discussed in more detail in this chapter.

Optimization was done for each of the scenario with respect to the variables and also with combination, in order to find the optimum combination with following criteria for the Microgrid.

- To meet the power requirement of the village in a secure way
- Financially sustainable
- Have minimum emission
- Majority supply from renewable sources

With the mentioned criteria scenario were designed for the load of the village to find out the best combination of technologies for energy supply and wind turbine was added to see the renewable penetration.

Scenario: 1

In the first scenario, renewable technology (PV) a diesel generator and storage batteries (Surrette 6CS25P) with a convertor based on the present fuel and renewable technology cost.

A schematic of the design is shown in figure: 26

The fuel prices fluctuate, to do a sensivity analysis for the following questions.

- If fuel prices goes up?
- If fuel prices goes down?

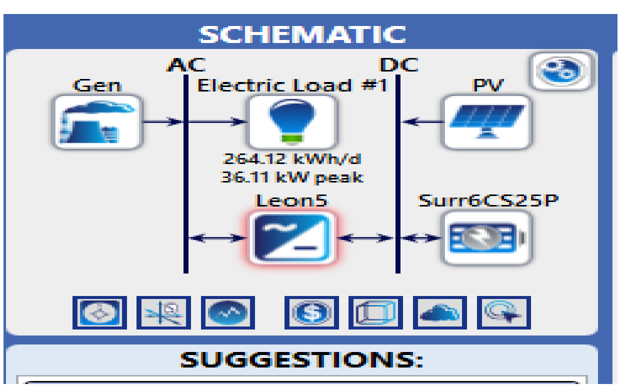

Figure: 26

Scenario: 2

This is same as Scenario 1 but the only difference is the future cost of renewable and fuel price goes low and up respectively. A question arise if the prices of renewable goes down and that of fuel prices as expect goes up, in this analysis it predict the cost of energy and its sustainability.

Scenario: 3

In this scenario a wind turbine was added to design to see the renewable penetration and sustainability at present cost of fuel and renewable. a couple of variables are in this scenario, wind speed and fuel price. Sensivity analysis was carried out for if fuel prices go up or if wind speed is lower than predicted. A schematic is in figure: 27

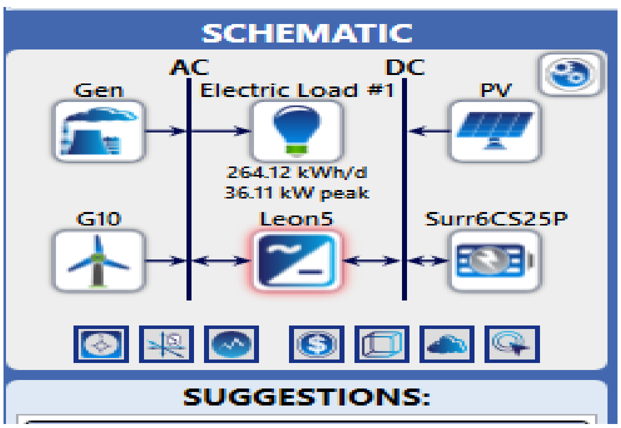

Figure: 27

Scenario: 4

this scenario is same as scenario 3 but the only difference is if the future prices of renewable technologies (Solar and Wind) as expect goes down and that of fuel price goes up.

8. Results and analysis

A few factors should be considered for any Microgrid energy supply system or an off-grid energy supply system.

In order to consider any suitable combination for power supply to the remote area are, supply should meet the demand with minimum or no unmet supply, high renewable penetration or generation with less or a fraction from fossil fuel, financially viable and reduce carbon emission.

These objectives were considered to identify the suitable energy system for the remote area.

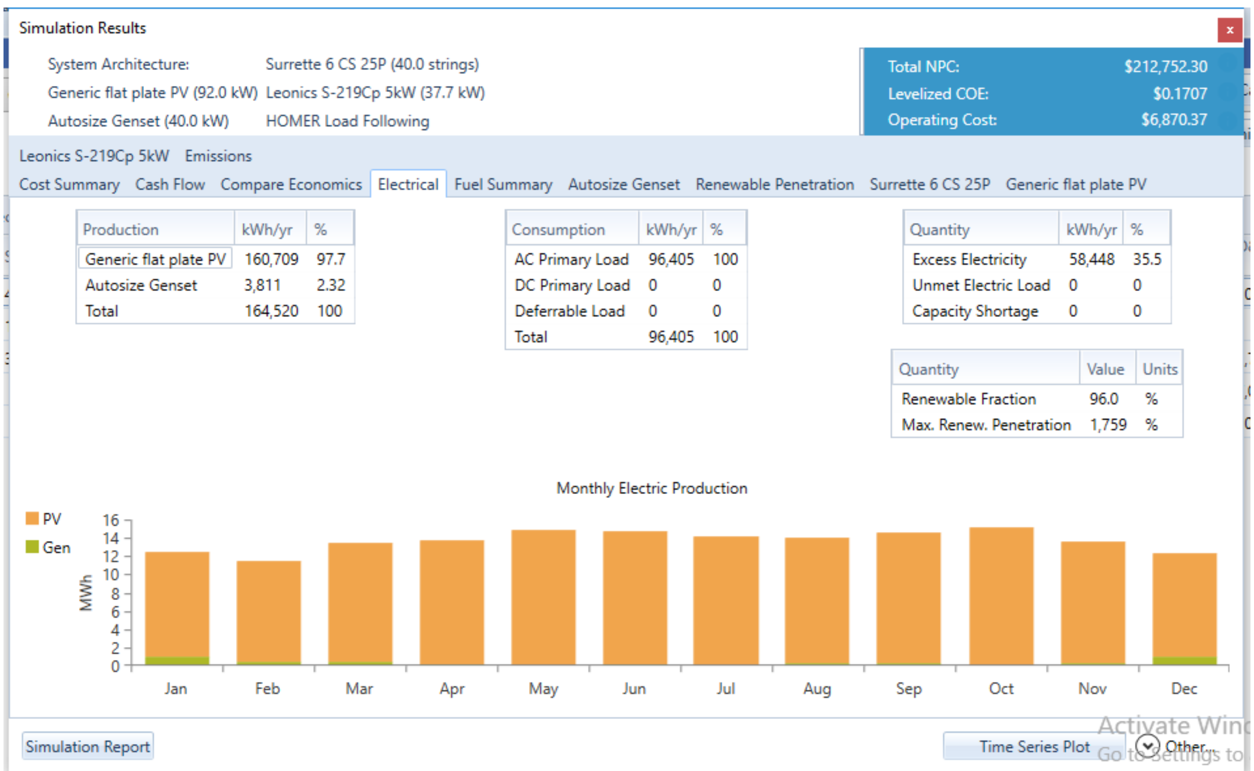

Figure: 28

Table: 17 Scenarios

Unmet Load (kWh/year)	Ren Frac (%)	CO2 Emissions (kg/year)	COE ($)	NPC ($)	PV (kW)	Surrette 6CS25P	Generator (kW)	Converter (kW)
0	96	3841	0.17	212752	92	40	40	37.7
62.7	100	0	0.198	247217	104	108	0	37
0	0	85517	1.488	608470	0	38	40	16
0	0	131048	0.75	946271	0	0	40	0

Discussion Scenario: 1

The simulations were completed using a combination of PV, storage (batteries) and a diesel generator. The diesel generator was optimized. The table 17 above shows the results from simulation and the results are of categorized from overall results.

In the above table 17 shows the results with the lowest net positive cost, the life cycle cost for the system.

In this scenario a combination of renewable along with fossil fuel system is ideal for supply of the power because it meet the criteria of selection up to some extent but not fully because the CO_2 emission is high which must be avoided and cannot be sustainable in future due to the supply problems of diesel. Supply issues are due to the location of the village and its remoteness as well. Even the renewable penetration or the percentage is quite encouraging and also the cost of energy is also the lowest compare to the other combination.

The second lowest is 100% renewable along with storage but the major problem in this combination is of only a single technology and unmet load. The intermittent nature of the renewable make it unpleased and the unmet power if want to increase the storage and number of PV will result in oversize of the system.

The last two combinations are unsuitable due to the fossil fuel for two reasons one the price of fossil fuel can go up and also the supply of fossil fuel to that locality.

Consequently none of the combination fulfills the all of the four criteria of selection for supply power to the remote area but the first is suitable for the supply of power in rest of the combination and full fill the three criteria of all the four for power supply to the remote area. As shown in figure 29 the four weeks in month of July and August the diesel generator starts or in operation only if there is no sunlight or the power storage is not enough to maintain a constant voltage. The renewable penetration is also near to ideal case but still the fuel supply is a major issue to that location.

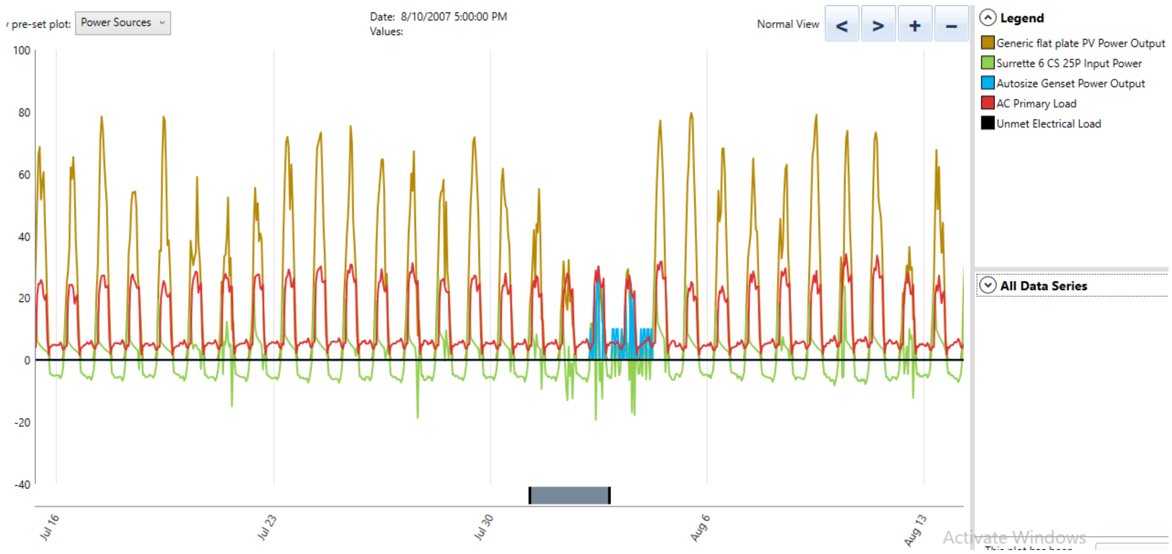

Figure: 29

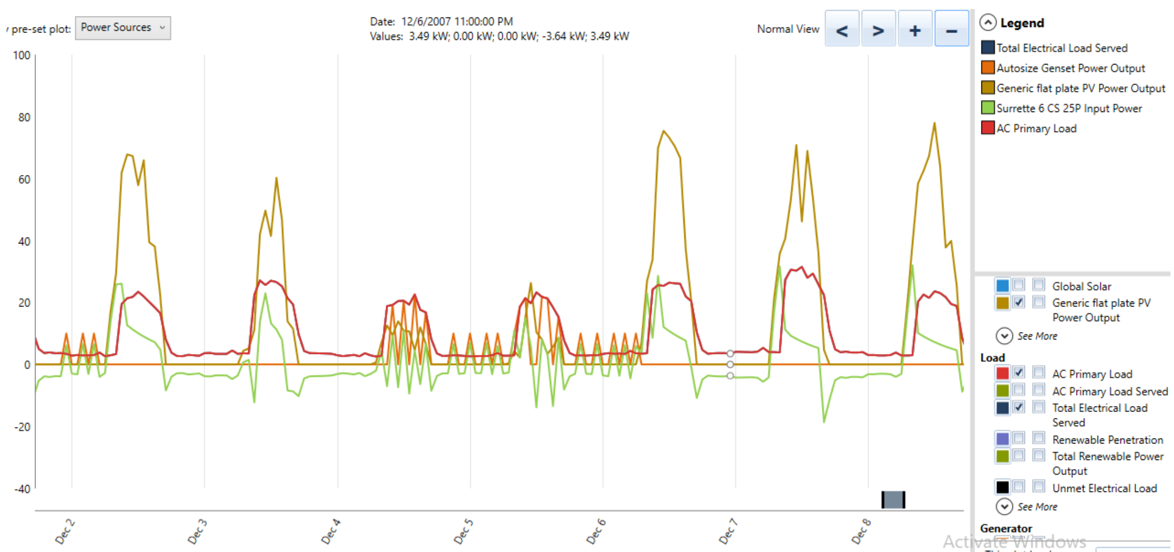

Figure: 30

Scenario 2

Table: 18 Scenario: 2

Unmet Load (kWh/year)	Ren Frac (%)	CO2 Emissions (kg/year)	COE ($)	NPC ($)	PV (kW)	Surrette6CS25P	Generator (kW)	Converter (kW)
0	97.4	2475	0.146	182036	121	34	40	37.7
53.3	100	0	0.159	197922	182	70		36.7
0	0	83549	0.578	719940	0	37	40	16.6
0	0	131048	0.899	1120000	0	0	40	0

The cost of the renewable was changed to the future cost and that of the diesel was also increased to the future price and run the simulation for the new cost and the categorized results were tabled in table 18.

The results show in scenario 2 considerably better than that of scenario 1. The penetration of renewable is higher than scenario 1.

The configuration with 100% renewable penetration is a better system but due to the unmet power ca not be considered because at remote area if power is not available at crucial time. There is several combinations available considering the criteria mentioned for the Microgrid system. Considering the security of supply and unmet power the system with 100% renewable but unmeet power cannot be considered. The next objective is the renewable fraction in power supply, if a system meets the load but with zero renewable fractions cannot be considered as well because the system will be not sustainable due the uncertainty of fossil fuel price and also security of supply. Similarly any system with no energy storage facility cannot be considered because the extra energy produce from renewable source when that energy is not in use just goes as waste.

Ideal system of scenario

There is no ideal system in scenario 2 but the one with PV, diesel generator and storage batteries is the best combination in respect of renewable fraction, lowest net present cost, lowest cost of energy and zero unmeet power. The ideal system is the one with 100% renewable energy, lowest net present cost, lowest cost of energy and reliability.

The better system in scenario was the diesel generator along with storage and PV. Similarly in scenario 2 the ideal system is a combination of PV, diesel generator and storage as mentioned earlier. It has zero unmet power and produce only 7475kg/year of carbon dioxide which lower than scenario 1 better system with respect of carbon dioxide, lower net present cost and also cost of energy.

Table 19 – Viable System for Scenario 2 (PV-diesel generator storage (batteries) hybrid)

Unmet Load (kWh/year)	Ren Frac (%)	CO2 Emissions (kg/year)	COE ($)	NPC ($)	PV (kW)	Surrette6CS25P	Generator (kW)	Converter (kW)
0	97.4	2475	0.146	182036	121	34	40	37.7

Figure 31 and 32 display the results of the viable hybrid system of scenario 2. From the figures, it identified that the power output from the PV surplus the energy required for the daily demand on a regular basis. The output reaches its peak during the day when solar radiation is at peak, and reduces through the evening. Due to the daily solar spikes, the surplus energy can be stored by the batteries and can be utilized at evening and night. The output of the generator is low when compared to the power output of the PV panels on a weekly basis, as it produces a small amount of electricity to meet demand and keep the system stable at time when no solar power available. For the week in August, the generator only operates when there is insufficient power to meet the demand especially in evening and night- Due to this daily surge of surplus energy production from PV, the batteries have enough capacity of energy to operate on a load following method – seen by the charge power of the batteries being in sync with the PV solar output – and that is why the generator is operated.

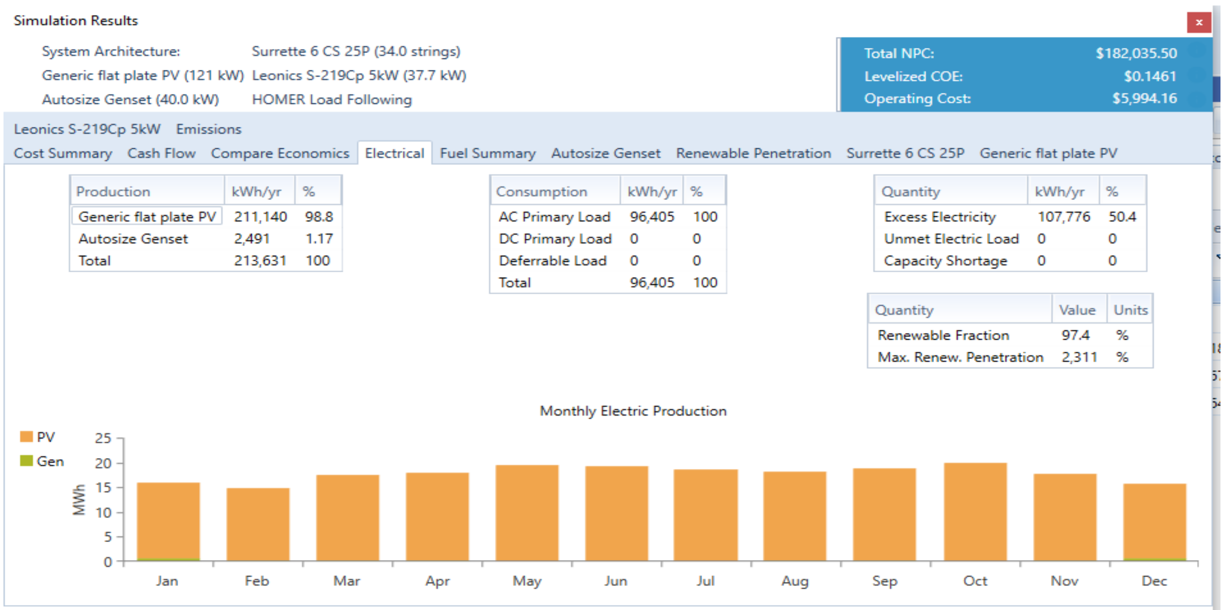

Figure:31

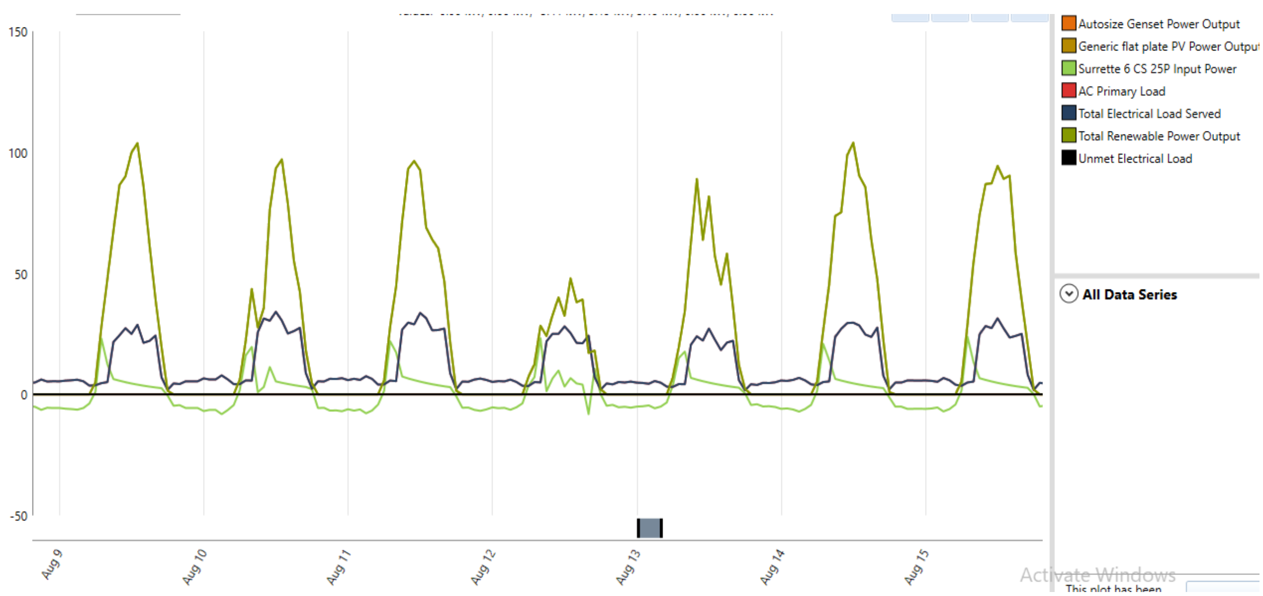

Figure: 32

The diesel generator is very important because of the intermittent nature of the renewable technology, as can see in figure 33 on 5 and 6 of December the solar radiation is weak, and the solar spike is not that enough to produce require power to charge batteries as well. The diesel generator provides stability and reliability to the system. The generator produce only to support the system at time it need stability and does not charge batteries because to keep the emission at lowest possible level.

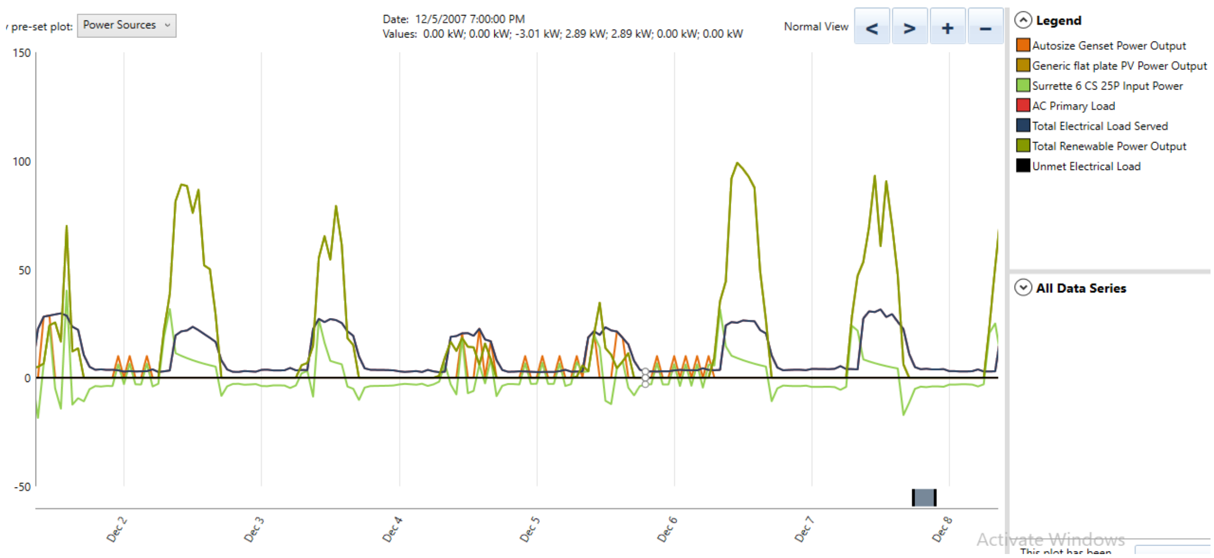

Figure:33

After analyzing scenario 1 and scenario 2 it is obvious that the hybrid system is best energy supply system for remote. The system consists of PV, diesel generator and storage batteries. The aim of adding storage is to utilize the renewable energy to its full capacity and reduce the level of green house gases to environment. The addition of generator provide stability and a high fraction of renewable and cost of energy make it a viable system for the remote corner of world population to help reduce the level of poverty from the world.

Next step is adding wind turbine to the system to observe results and its financial viability for remote area.

Scenario: 3

In this scenario a wind turbine was added to already design system and run simulations for the best optimal combination with respect to the criteria already set for the design system for rural area.

The categorized results with different combination and net present cost are tabled below.

Scenario: 3 results table:20

Unmet Load (kWh/year)	Ren Frac (%)	CO2 Emissions (kg/year)	COE ($)	NPC ($)	Wind turbine	PV (kW)	Surrette 6CS2P	Generator (kW)	Converter (kW)
0	95.5	3309	0.160	199617	1	78.3	31	40	35.8
0	96	3849	0.171	212752	0	92	40	40	37.7
53.3	100	0	0.183	227588	1	113	74	0	35.0
62.7	100	0	0.198	247217	0	104	108	0	37.0
0	74.1	23519	0.337	420015	8	0	62	40	26.2
0	0	83517	0.488	608470	0	0	38	40	16
39.2	100	0	0.673	837887	21	0	278	0	132
0	0	131048	0.759	946271	0	0	0	40	0

In this scenario, wind and PV technology is established along with diesel generation, and so renewable are less expensive. This reflection is brought to light by the results, as six combinations out of the eight have higher renewable fractions. These 6 combinations have varying proportions of diesel generation, ranging from 26.0%. Although there are 100% renewable systems, these three combinations have a significant unmet load per year when compared to the systems which consider diesel generation.

Autonomy of any energy system is an important objective to meet, the unmet load is an important factor of the energy system, as it reflects efficient the system could be autonomous. Energy systems which have unmet load could be potentially unstable during operation. It is important that storage is essential in any energy system in order to take advantage of the power generated from renewable technology. The peak supply of renewable may not be at the peak demand, and so any surplus energy produced could be stored and used later when renewable is not available. This can increase the renewable fraction in total energy supply.

Any combination of renewable technology which supplies 100% renewable could not meet the demand and the first objective is not met for any Microgrid system. So any such combination cannot be considered for rural energy supply.

The two best option with renewable fraction of 96.5% and 96%. Considering the criteria and analyzed the result. The best or ideal system is the combination of PV. Wind turbine, diesel generator and storage. The other is not as close to the four criteria as it is. The most suitable solution from the available combinations would be slightly relied upon diesel generation, with 31KW Surrette 6CS25P batteries as storage, 78.3 kW of PV and 10kW wind turbine with a 96.5% renewable fraction. The hybrid system has lowest carbon emissions of 3309 kg per year; it takes advantage of the energy generated from the PV array and wind turbine. The system is said to be financially viable costing 199616 dollars, one of the substantially cheaper options with zero kWh per year of unmet load and lowest cost of energy.

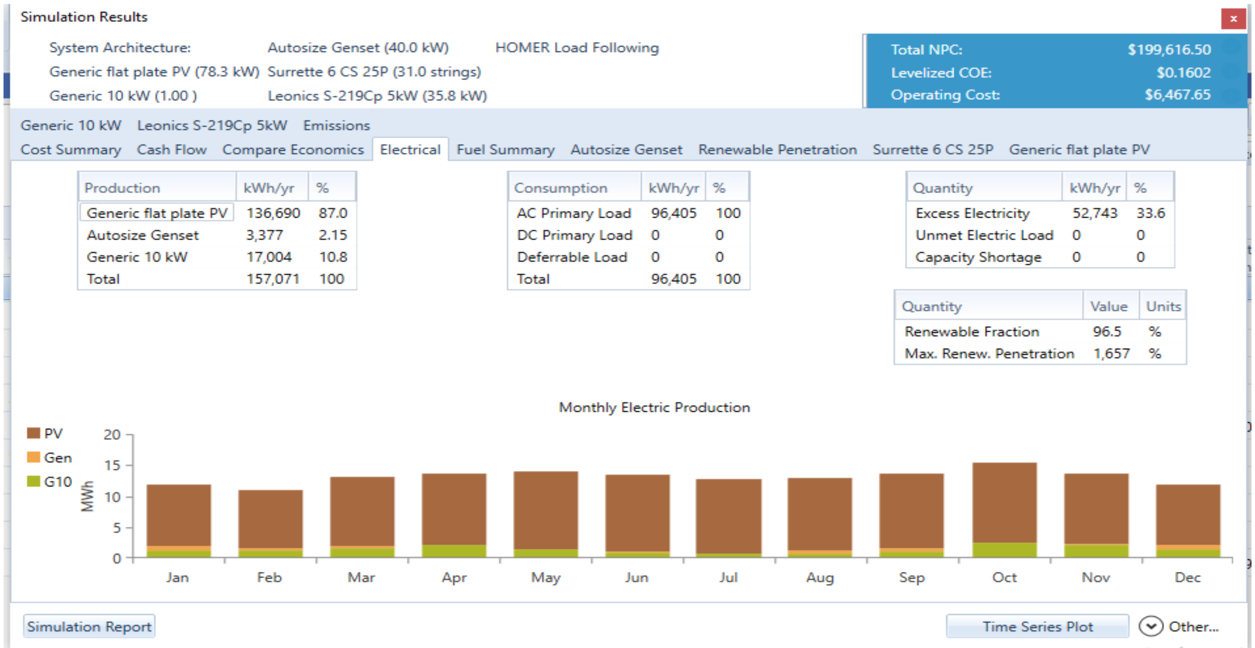

Figure:34

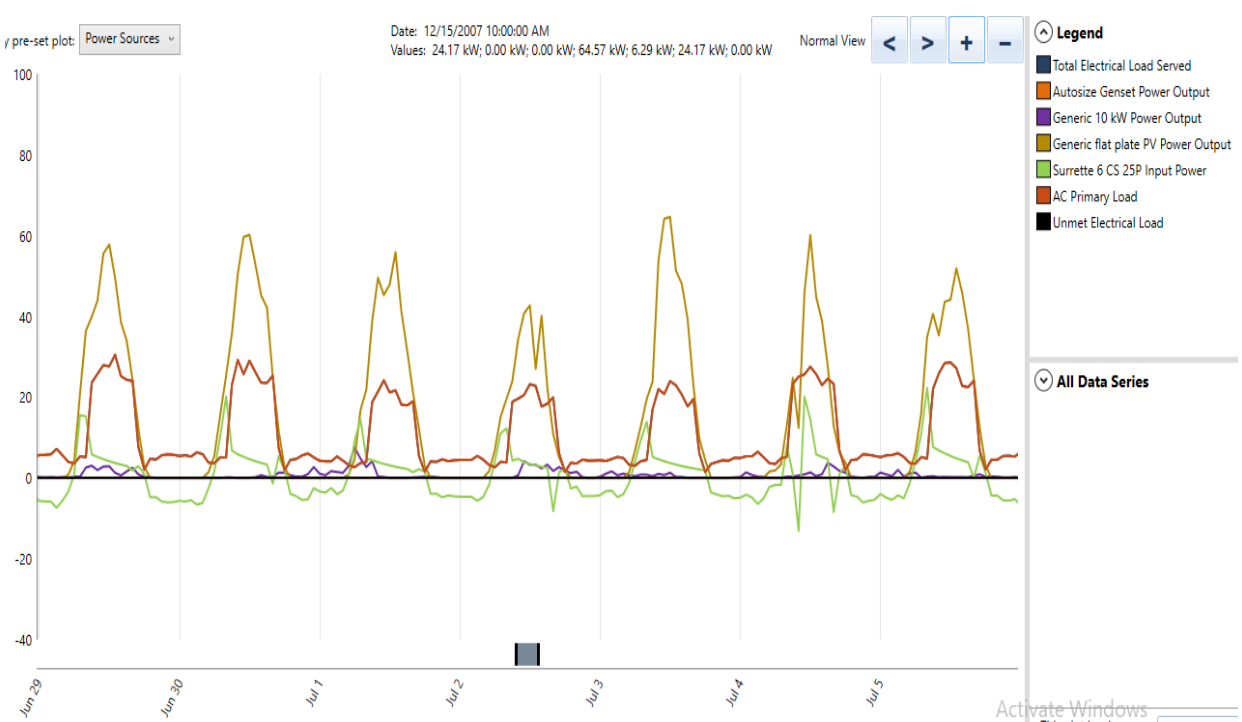

Figure:35

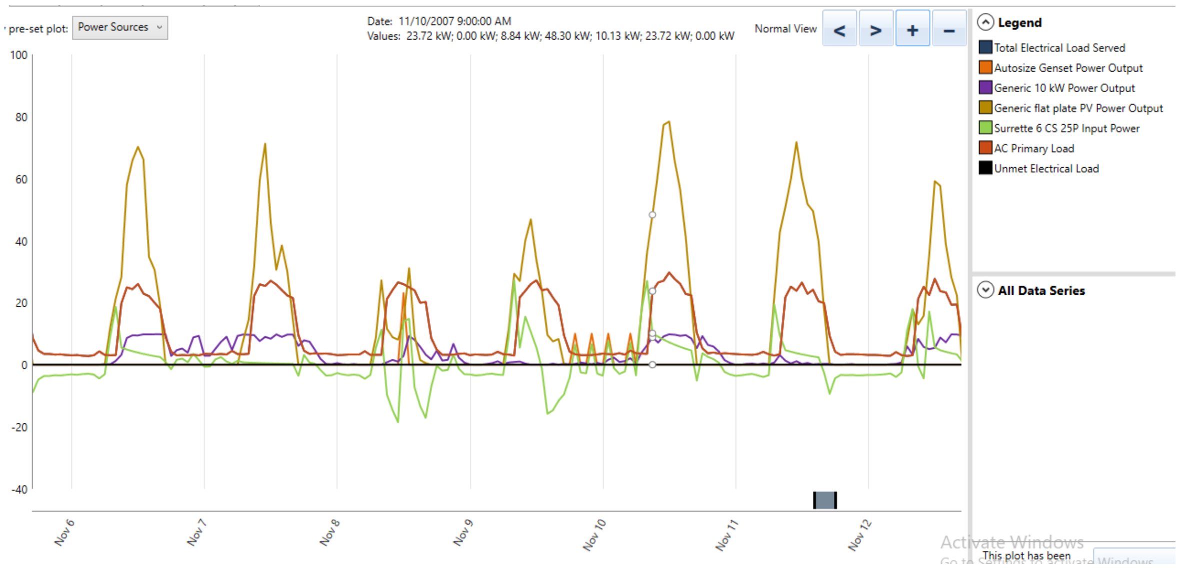

Figure:36

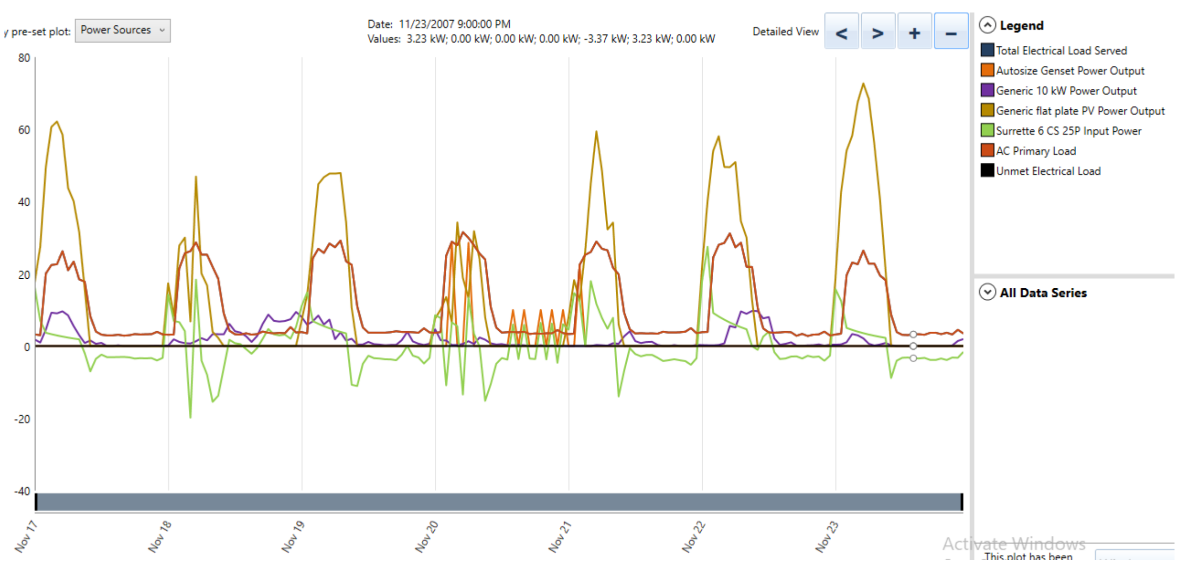

Figure:37

Figure 35, 36, 3 shows the demand for a week in July, November and December, with the relevant power outputs for the ideal system generation sources. The generation sources include renewable sources (78.3 kW PV array), wind turbine, batteries and generator. The generator operates in cycle charging. It produces power in the hours of the night; allow meeting demand and providing constant voltage. The time of the renewable power generation the generator does not operate (unless renewable supply is low) as the demand is met through the renewable power generated and the surplus energy stored in the Surrette 6CS25P batteries. However, when there is no renewable power supply, the Generator operates in a load following mode, supply electricity to meet the demand with minimal surplus energy.

The next step is to model for scenario: 4

Table: 21 Scenario: 4 (Future prediction with cost trend)

Unmet Load (kWh/year)	Ren Frac (%)	CO2 Emissions (kg/year)	COE ($)	NPC ($)	Wind turbine	PV (kW)	Surrette 6CS25P	Generator (kW) Converter	Converter (kW)
0	98	1772	0.133	166120	2	83.3	31	40	34.6
563	100	0	0.141	176107	2	130	54	0	35.2
0	97.4	2475	0.146	182036	0	121	34	40	37.7
53.6	100	0	0.159	197922	0	182	70	0	36.7
0	86.3	12679	0.300	374233	12	0	75	40	31.0
39.2	100	0	0.512	698264	30	0	224	0	41.2
0	0	83549	0.578	719940	0	0	0	40	16.6
0	0	131048	0.899	1120000	0	0	0	40	0

Scenario 4 simulations were run with lower costs for the renewable technologies and a higher fuel price for diesel to find out future predictions for energy system. The results of systems with the lowest net present cost are displayed in Table 21.

The results show higher renewable fractions with zero unmet loads per year. Although, the systems which have 100% renewable fractions have an unmet load which is not suitable to be implemented into a remote area although these combinations having theoretical zero carbon emissions.

The configurations of renewable and diesel generators as part of a hybrid diesel-renewable system have a significant high proportion of renewable fractions in energy supply system. However, the configurations with renewable fractions of 90% or above produce carbon emissions – because of reliance and operating hours of the generator.

A number of suitable options, with considering the criteria mentioned previously, are available. To account the unmet load and autonomy of the system, the systems which are 100% renewable fractions are unsuitable and out of consideration. The next criteria are the renewable fraction. The combination with zero renewable generation cannot be considered for the ideal system; because of sustainability of fuel prices are unstable due to reduced fossil fuel reserves. The system will also unsuitable if it has no energy storage, the remaining criteria, the two suitable options are the systems with 98% and 97.4% renewable fractions and has the lowest net present cost.

Ideal system for Scenario 4

Combination of the ideal system for scenario 4 is listed in Table 14. The system consists of PV panels, wind turbine, batteries and a diesel generator. It has no unmet load, produces 1772 kg of carbon emissions in a year – which is lower compared to the ideal system in scenario 3.

Table: 22

Unmet Load (kWh/year)	Ren Frac (%)	CO2 Emissions (kg/year)	COE ($)	NPC ($)	Wind turbine	PV (kW)	Surrette 6CS25P	Generator (kW) Converter	Converter (kW)
0	98	1772	0.133	166120	2	83.3	31	40	34.6

The system has a renewable fraction of 98% and has a net present cost of 166199$. This system is wind, PV, diesel and batteries hybrid system. It provides a reliable power due to the small portion of diesel generation.

Figure 38 shows the power output and demand for the system displayed in Table 22, for weeks in August, November and December. From the figure, it is obvious that the power output from the PV exceed the energy required for the daily demand on a regular basis. The power output from PV reaches its peak during the day when solar radiation is at a peak, and reduces through the evening as the night approach. Due to the large daily extra power, the surplus energy can be stored by the batteries which provide power in evening. The power output of the generator is relatively low compared to the output of the PV panels and wind turbine on a weekly basis. it produces a small amount of power to meet demand at time solar and wind are unable due to its intermittent nature and keep the system stable. For the week in August, November and December the generator only operates when there is insufficient PV and wind power to meet the demand.

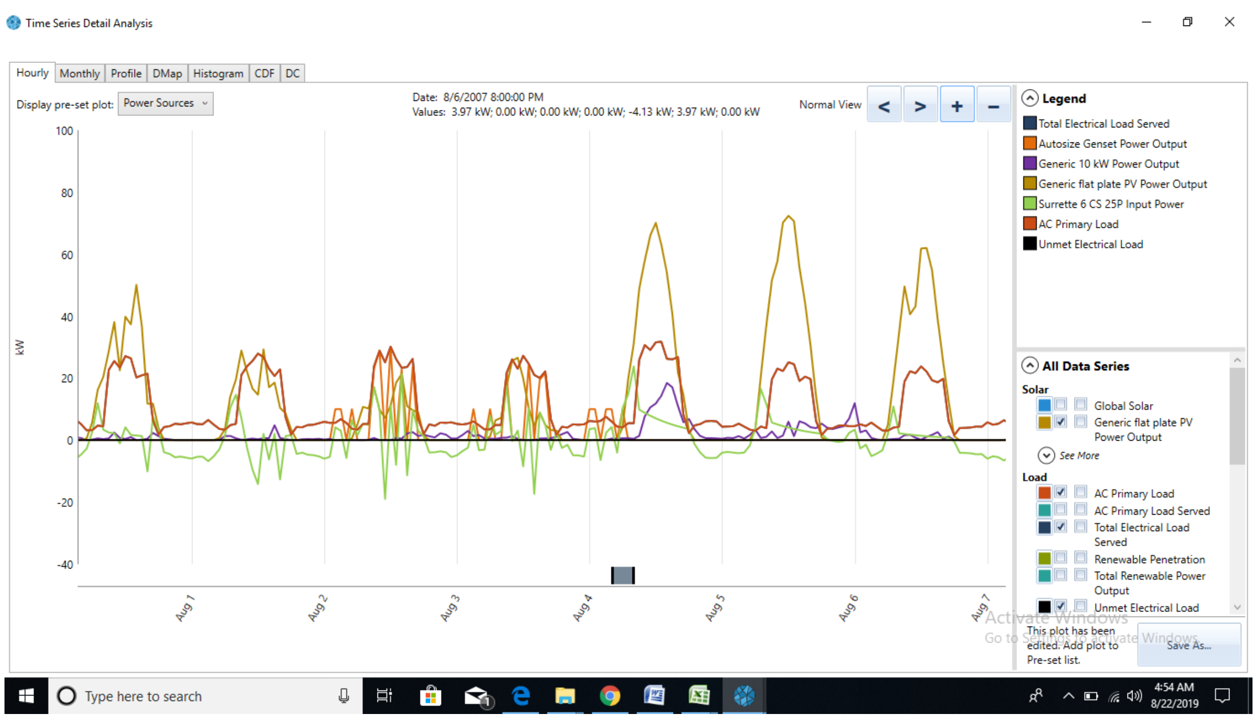

Figure: 38

Figure:39

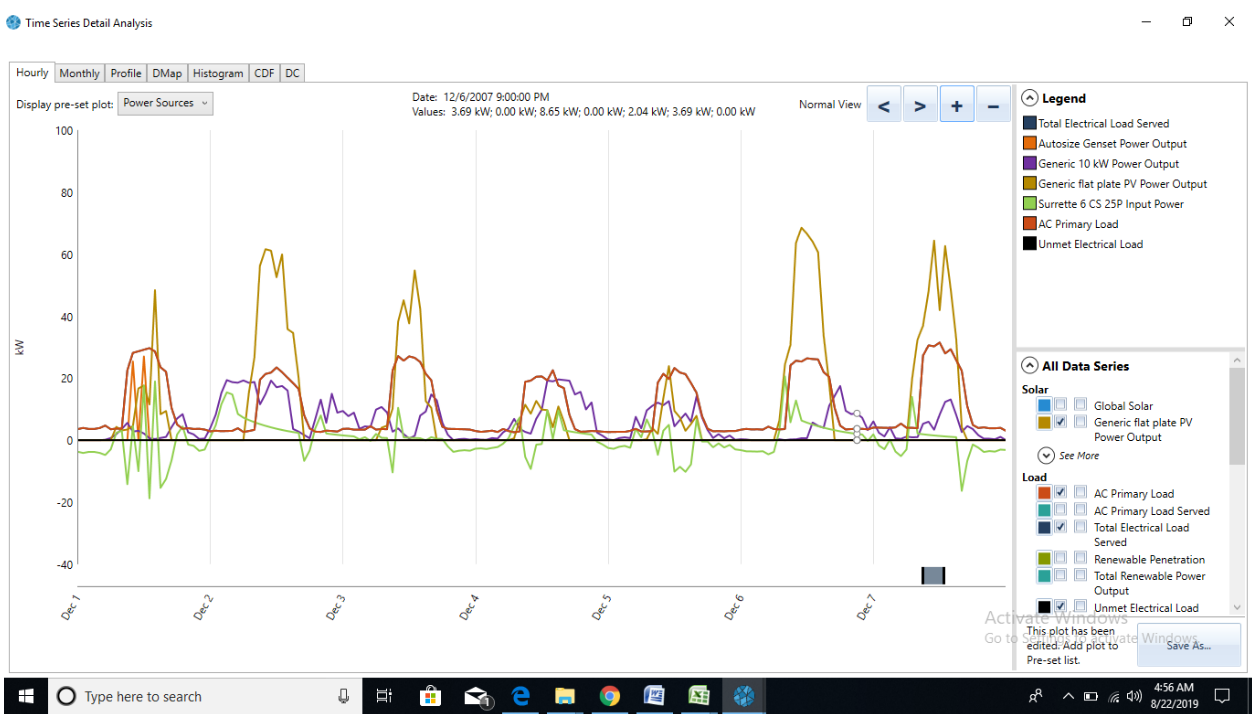

Figure:40

The diesel generator provide stability to the energy system because renewable resource are intermittent in nature. As during the winter, there will be less solar radiation and in such instances the wind might not able to produce enough diesel generator will need to be switched on more frequently. An example is given in Figure 40 for a week in December when PV and wind generation is low on number of days. On these occasion, the generator is switched on to produce enough power to meet the deficit between the supply and demand.

From scenario 1, 2, 3 and 4 it is evident that the most suitable combination for case study would be a PV, Wind, Diesel generator system with energy storage to fully utilise the energy generated from solar resources and wind. This system has the lowest carbon emissions, and has a high renewable fraction with a diesel generator which provide stability due to the intermittent nature of the renewable sources. It is also financially viable at present as well as when considering future expected costs of renewables.

9. Sensitivity Analysis

Table: 23 A system with storage and without storage

Ren Frac (%)	CO2 Emissions (kg/year)	NPC ($)	PV (kW)	Surrette 6CS25P	Generator (kW)
60.2	4841	212752	132	0	40
97.4	2475	182036	92	70	40

It is essential to note the effect of energy storage variables on the energy system. A comparison is presented in Table 23. It is obvious from the table that the addition of storage capacity decreases the cost of energy and also decrease required PV capacity. It is very significant because any extra power generate during the peak hour of renewable energy generation. The excess power can be stored and then utilizing this energy in times of increased demand. The storage in turn reduces the reliance on diesel, in turn lowering the emissions of the system. As more energy generated from renewable is utilized, there is an increased renewable fraction, regardless of the renewable capacity being lower than the system without energy storage.

Table:24 Effect of increased fuel price

Unmet Load (kWh/year)	Ren Frac (%)	CO2 Emissions (kg/year)	COE ($)	NPC ($)	PV (kW)	Surrette 6CS25P	Generator (kW)	Converter (kW)
0	96	3841	0.17	212752	92	40	40	37.7
0	97.4	2475	0.146	182036	121	34	40	37.7

Table 24 shows the effect of increasing fuel price. As the fuel price is increase the capacity of renewable also increases. it is because the renewable technology become more financially completive especially when the diesel price reaches $1.5/L. The increase in diesel price result in an overall rise in costs as the use of generator is reduced as a result of fuel becoming more expensive.

10. Future Work

The results from investigation of design model concluded that the possible energy supply system for the rural area of Mohmand agency Village Soran of K.P.K Pakistan would largely a combination of PV, Wind Turbine, storage batteries and a diesel generator as back up. The optimum combination might change if more storage or better energy storage is provided in future. If future work is carried in line with present work it may be applying more power demand and storage of water for producing energy by using hydrokinetics.

11. Conclusion

The addition of storage is important in an energy system which features significant renewable generation. Energy storage increases the stability of a system and also increases the renewable fraction because larger fraction of the load is met using renewable energy when available. Wind turbine provide a small fraction but important because it produce at time of lower power output from PV in the case study. The diesel price is susceptible to number of reason but drastic increases due to the limited reserves of fossil fuels and could be vanish soon. As sensitivity analysis shows, the rise in diesel price results in the increase of the renewable technology capacity of energy system as it becomes more financially viable. With the present costs of renewable technology, it is not difficult to design an energy system which features mainly renewable generation and is financially viable. Nevertheless, as the cost for renewables is deckling, this would encourage more renewable capacity in energy system. In turn of decrease in cost of renewable energy will reduce the carbon emission to environment because fewer generators will operate for fewer hours.

The homer does not consider all the important factors for a remote energy system it only point out financially viable energy system combination. The Homer has some limitation because it consider a combination or a single technology with high renewable fraction but does not consider storage and financially viable. This is one of the limitations of the software.

It can be concluded from the analysis of energy system design for the remote village Soran, District Mohmand, K.P.K, Pakistan, that a suitable off grid energy system would be consist of wind turbine, PV, Batteries and a diesel generator, which operates only at time when renewable is not sufficient to meet the demand of the village and provide stability to the system. Because the renewable source of energy is intermittent in nature means cannot be relied.

It is important that the fuel prices may go up and, but the storage of renewable could be increase and better form could be in market to replace diesel generator.

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