TECHNICAL AND ECONOMIC EVALUATION OF 50 MW SOLAR POWER PLANT IN QUETTA

By

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Reg# 00000277804

Session 2018-20

Supervision by

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MASTER of SCIENCE in

ENERGY SYSTEM ENGINEERING

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National University of Sciences and Technology (NUST)

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THESIS ACCEPTANCE CERTIFICATE

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DEDICATION

This thesis is wholeheartedly dedicated to Almighty Allah, thank you for the guidance, strength, power of mind, protection and skills and for giving me a healthy life and my beloved parents, who have been my source of inspiration and gave us strength when I thought of giving up, who continually provide their moral, spiritual, emotional, and financial support. Secondly, I dedicate this work to my faculty supervisor Dr. Muhammad Hassan and my GEC members who helped me in thick and thin situation and shared their words of advice and encouragement to finish this thesis.

ABSTRACT

Universal electricity access is possible with the help of rural electrification which is considered to be a fundamental step to fight energy crises. By 2030, it is assumed that every individual will be able to get electricity access irrespective of their area i.e., city or remote area. Off-grid renewable energy is considered to be a solution for this problem because on-grid rural electrification will be costly. Pakistan is an underdeveloped country and facing worst energy crisis for the last two decades. In recent years the gap between demand and supply has multiplied and with increasing demand this situation has triggered a full power shutdown in urban areas for 10–12 hours and in rural areas for 16-18 hours. The prime objective of this study is to evaluate the techno-economic feasibility of 50 MW solar farm in Quetta, Pakistan. Solar radiation data was collected from radiation device i.e., Tier 2 weather station with rotating shadow band Irradiometer that have been installed in the Baluchistan University of Information Technology Engineering and Management Sciences Quetta (BUITEMS Quetta) by the World Bank and the USAID. The devices collected data after every 10 minutes that were installed in the specified areas. The data was collected for one year and techno economical evaluation of the data was carried out. For the economic feasibility evaluation of the proposed plant the LCOE (Levelized Cost of Electricity) model was used, and it is estimated that the energy produced by proposed power plant will cost 6 PKR/KWh. Technical evaluation of the power plant reveals that 91.980 GWh of electricity can be produced per year. At the capital cost of $59.689 M, O&M cost of $0.9M/yr, and 10.5498% discount rate, and the economical evaluation of proposed PV plant produces electricity at a rate of 0.0385 USD/kWh or 6.09 PKR/KWh. The results of this study depict that 50MW PV plant will be feasible for Quetta city. As the LCOE for this evaluation was three rupees less than minimum quotation of Quetta Electric Supply Company (QESCO).

Keywords: *50 MW, Technical evaluation, Economic feasibility, Quetta, Photovoltaic, Solar Radiation*

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

LCOE = Levelized Cost of Electricity

IRR = Internal Rate of Return

CF = Capacity Factor

CHAPTER 1

Introduction

The growth of modern economies is characterized by availability of energy mainly electricity. In today's world in order to carry out activities, the flow of electricity is mandatory because every device is chargeable and needs electricity [1]. Fossil fuel is considered one of the major success factor for a country as it is the major source of energy that is being utilized globally. For economic growth, energy is an essential input. As energy sources in the country are limited, the production of renewable sources of energy and the use of energy efficient technologies must be urgently addressed. One of Pakistan's main areas of focus is the exploitation and development of different kind of resources and the availability of energy at an affordable price[2]–[5]. The country is blessed by diverse non-conventional energy sources and the Ministry's efforts will encourage viable technologies that can help the poorest people in the remote areas of the country [6].

The electricity supply is limited, and Pakistan is facing its worst energy crisis. In recent years the gap between demand for electricity and supply has increased and is highly evident in the summer. This has triggered a full power shutdown in urban areas for 10–12 hours and in rural areas for 16-18 hours[7]–[9]. Energy shortages impact not only people's lives, but also the country's economic growth. The long power outages and tremendous economic losses for the country have severely affected all industries, including agricultural, industrial, transportation, home and power generation[10], [11]. In Pakistan's overall energy mix, the current share of renewable energy is inadequate[12]–[16].

By using fossil fuels, the nation meets its energy requirements. Great reliance on fossil fuels has an impact not only on the national industry but has also contributed to several environmental hazards, including greenhouse effects, CO_2, global warming[17] and erratic weather patterns. In addition, due to the overuse of fossil fuels, renewable resources are being depleted. Therefore, a new energy economy needs to be created [18].

1.1 Renewable Energies

Unlike traditional sources of energy, renewable energy is collected from natural sources i.e. sun, water and wind etc. The phrases "green energy," "clean energy," and "alternative energy," are also used to refer to renewable energy [19].

The renewable energy forms are as follows:

- Solar energy
- Wind energy
- Biomass energy
- Hydropower
- Geothermal

Renewable sources of energy are being used in this new economy to generate energy that, on the one hand, will minimize the carbon import bill and, on the other hand, reduce climate challenges[20]–[23].

In the global average temperature increases of 0.6° C has already occurred in this last century mainly because of the greenhouse gases emitted to the atmosphere[24], [25]. If this pattern persists, it will jeopardize our environment and ecosystem's stability. Solar energy is the most critical energy solution to produce competitive, realistic and large- scale renewable energy sources, which can replace fossil fuels [26].

1.2 Solar energy

Solar energy is produced by the light power and radiant heat of the Sun. This is the simplest and most abundant energy source [27]–[29]. Since ancient times, people use a variety of inventions and ever- developing technology to harness this energy. In just an hour from the sun, this Planet receives more energy than it uses over a year all over the world. The process of nuclear fission inside the sun produces this energy [30].

Solar power has the potential to overcome all the challenges among various. It has proved to be the world's best-priced technology. Global Solar PV capability hit 402 gigawatts (GWs) by the end of 2017, according to the International Energy Agency. It will increase by approximately 580 GW further and will contribute to growth of renewable power [31].

Pakistan is situated geographically in the sun's belt and receives big sunshine all year round. It is very important to leverage the available solar energy resources in order to resolve current energy problems. In the meantime, investment in the government and private sector is very necessary to unlock its true potential [32].

1.3 Photovoltaic (PV): Technology-The future of Solar Energy

Photovoltaic means light electricity and direct current (DC) is generated using the conversion of visible light through a special semi-conductor diode called PV cell. Infrared (IR) or UV rays can be converted into DC power by some PV cells [33]. The common application of Solar Electricity are solar energy toys, calculators, and phone call boxes [34], [35]. Photovoltaic cells are now part of solar power systems that are now increasingly important as an alternative power source.

Photovoltaic cell consists of two or more semi-conductive layers that are thin and typically made up of silicone. Electric charges are produced when this silicon layer is exposed to light and can be extracted as a direct current (DC) with the use of metal contacts. There is a small electrical output in one single cell, so that several cells are incorporated into a photovoltaic module, also known as the plate. The concept and basic building block of entire PV cell is this module and several modules for the desired electric power can be assembled [36]. Modern PV cells can turn 10 to 20 percent of light into electricity. The quality will be increased in the coming years to achieve even better results [37], [38].

Photovoltaic systems have various types i.e. thick film silicone, amorphous silicon, monocrystalline silicon cells, multi crystalline silicon cells etc. [39], [40]. The grid linking PV system is the main field of concern today because local power network is linked with these PV systems. Meanwhile the electricity generated throughout the solar hours can be sold to a utility or can be used immediately. Often, electricity can be purchased from the network when the sun goes down[41]. Standalones are used for photovoltaic systems that have trouble linking or inaccessible grid power supplies. Monitoring stations, radio repetition stations and street lighting applications[42].

In the developing world, PV technology is most used. The device is the best way to deal with distant locations and the issue of unstable or inexistent power grids. The most economic choice is the photovoltaic power supply in this sector.

1.4 Objectives

- To analyze the potential of solar energy in Pakistan as a source of distributed generation
- To provide detailed technoeconomic feasibility for electricity generation from solar energy
- To provide a detailed analysis of different aspects of economic and technical feasibility
- To mitigate the impact of energy crisis in far flung areas of Balochistan through rural electrification

1.5 Scope of Study

This research focuses on potential assessment of solar energy in Quetta. This study focusses on multiple aspects of technical and economic evaluation of 50 MW solar farm in Quetta, Balochistan, Pakistan. The study investigates the possibility of how solar power can be utilized to meet the increasing power demand in Quetta through rural electrification.

1.6 Limitations

The major limitation of the study is that the data used for the analysis was taken from nearby weather stations. We cannot make our own primary data as it is a long and extensive process and will highly affect the research time period. This data will only provide the approximation of electricity generation but for true results data should be measured at the proposed location.

Summary

The growth of modern economies is characterized by electricity. To work properly, energy is required for all human activities such as education, health, agriculture, and jobs. Without proper use of oil, a country cannot succeed. In the global average temperature increases of 0.6° C has already occurred in this last century mainly because of the greenhouse gases emitted to the atmosphere. If this pattern persists, it will jeopardize our environment and ecosystem's stability. Solar energy is the most critical energy solution to produce competitive, realistic and large- scale renewable energy sources, which can replace fossil fuels. In the developing world, PV technology is most used. The device is the best way to deal with distant locations and the issue of unstable or inexistent power grids. The most economic choice is the photovoltaic power supply in this sector.

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CHAPTER 2

Literature Review

In 2019, Ying Wanga along with his team conducted study on “Strategic renewable energy resources selection for Pakistan: Based on SWOT-Fuzzy AHP approach”. In the study, the factors that affect the renewable energy technologies internally and externally i.e. Threats (SWOT) analysis, Opportunities, Weaknesses and Strengths have been studied. From the multi-perspective approach (i.e., socio-political criteria, technical, environmental and economic), the Fuzzy AHP (Analytical Hierarchy Process) method is applied. It was observed during the course of this research that the electricity crises of Sindh and Balochistan can be fulfilled by wind energy only, whereas second and third ranks were given to solar and biomass energy respectively. For sustainable development of the country it is therefore suggested that, in order to increase energy security and to mitigate the current energy crisis the government should exploit renewable [1].

In 2020, Noman Shabbir conducted a study on “Economic Analysis and Impact on National Grid by Domestic Photovoltaic System Installations in Pakistan”. The study shows that the mainstreaming of solar energy can diversify the energy mix of Pakistan and can reduce the energy dependency on a single source, especially on fossil fuels that can indirectly reduce the carbon footprint [2].

In 2016, A report of Enertech Quetta Solar (Private) Limited concluded that the 50 MW power plant will provide power to The Quetta city and the adjoining areas of Quetta, Pishin, Bostan and Kuchlak District. It will be the only local source of power other than Habibullah coastal thermal power project which was setup in 1999. The power plant will not only provide cheap electricity but also improve the overall Grid in the region and improve the voltage levels [3].

In 2018, T.Z Mohammad conduct research about “Modelling and Simulation for installation feasibility of standalone photovoltaic system for Quetta, Pakistan” and compared two geographical sites of Quetta, Pakistan and Copiapo-Chamonate (CC) and concluded that Quetta site can produce 3.96% more energy as compared to CC due to 10% more solar fraction and 0.7% more performance ratio [4].

In 2018, Syed Ahsan Ali Shah conducted "Techno-economic analysis of solar PV electricity supply to rural area of Balochistan" and calculated the optimal tilt angle and the potential of sunlight when it enters the surface of solar panel in horizontal position. It was concluded that, at optimal angle of 29.2° in Quetta the 10.78% increase of solar radiation is possible [5].

In 2018, Naveed Ur Rehman studied "Renewable energy technologies in Balochistan: Practice, prospects and challenges" and the collect primary data about electricity price by survey, and secondary data based on the available literature and studies. According to the survey data,7% of people are very satisfied from the current prices of electricity in Pakistan. 18% are slightly satisfied. The people who are neither satisfied nor unsatisfied are 21 %. 19 % are slightly dissatisfied while 35% of people in survey are very dissatisfied.

In 2017, Fazal Muhammad studied "Different Solar Potential Co-ordinates of Pakistan" and presented review of "Solar potential of different Pakistan Co-ordinates and cotemporary development to harness the solar potential to meet power crisis". The research stated that to meet the energy demands in Pakistan, we require to generate 2000 MW per year using Solar plant while the estimated solar potential is 100,000 MW [6].

In 2016, Tasneem Zafar conducted research on "Integration of 750 MW renewable solar power to national grid of Pakistan – An economic and technical perspective". The purpose of this paper is to explore the economic and technical impact of connecting a mega-scale PV plant to the national grid. The area of Kharan in Balochistan province was chosen due to desired solar irradiation (7–7.5 kWh/m2 /day). Real time simulations were run in power system planning software PSS'E. Load simulation results positively confirm that connection of the proposed 750 MW plant does not cause any load flow violations and the recommended short circuit current levels of the system is preserved [7].

In 2015, S.M. Sajed Sadati published "Energetic and economic performance analyses of photovoltaic, parabolic trough collector and wind energy systems for Multan, Pakistan" and presents the performance analysis for PV, PTC and wind power plants with 10 MW capacities is performed with respect to electrical energy production based on hourly meteorological data in TMY format for Multan, Pakistan. The study shows that PTC and PV systems are found to be feasible based on the calculated LCOE (levelized cost of electricity) [7].

In 2013, Anjum Khalid published "Study of economic viability of PV electric power for Quetta, Pakistan" and estimated electric power generation by a simulation- based software (RET screen) and stated that PV power plant generates the highest electricity and has potential to generate 23.206GWh electricity in a year at Quetta, Pakistan [8].

2.1 Renewable Energy

The concept of renewable energy resources is that of energy sources derived from natural' and 'immediate environment continuous energy flows.' The word "natural" implies that unlike fossil-based energy resources which require human effort and exploration to make them accessible, they do not require human efforts to achieve their flow or their environmental availability [3].

Renewable energy supplies were considered to be in line with sustainable development strategies compared with non-renewable energy sources, for instance fossil and nuclear energy, which have the problems associated with limiting energy resources and detrimental effects on the environment.

Different practices involving energy use, resulting in the depletion of energy supplies and the destruction of the atmosphere, are consuming the planet's natural resources to the breaking point. Our planet requires a real-life check when it comes to the future of electricity. Any nation or region worldwide has economic growth and development linked to the degree of its energy use [7].

Due to the numerous developments, particularly the Industrial Revolution in the 19^{th} century has geared up by the discovery of fossil fuels like coal, oil and gas. In the 1920s, coal represented the largest proportion of the world's energy supply. It decreased to just 26 percent at the beginning of the 1990s, with 40 percent of the world's energy requirements being consumed by oil. Fossil fuels are now 100,000 times faster depletion than their forming rate [9][10].

2.1.1 Merits & Demerits of Renewable Energy

Merits

- Renewable energies are available free of charge in nature
- Negligible amount of pollution is generated
- The sources are never-ending
- The gestation period of these sources is very low [11 – 14].

Demerits

- Energy is typically available from these sources in diluted form.
- The cost of using non-conventional energy generation is generally high although readily accessible in nature.
- Unknown availability: the energy flow does not depend on the human regulation but depends on different natural phenomena.
- Difficulties in the transport of certain energy forms

2.2 Electricity Demand Status of Pakistan

The installed electricity generation capacity reached 37,401 MW by 2020, according to the Pakistan Economic Survey 2019-20 [15]. The total maximum demand from residential and industrial property is almost 25,001 MW, and the transmission and distribution capacity is about 22,001 MW. The demand peaks lead to a shortage of approximately 3,000 MW. This additional 3,000 MW is not necessary, even though the country's high demand is far below its installed capacity of 37,402 MW [16].

Table 2.1 Power Consumption of Different Zone in Pakistan [17]

Sector	**Consumption of Power**
Household	48%
Commercial	8%
Industry	27%
Agriculture	9%
Others	8%

Pakistan is pursuing a total supply of renewable (excluding large hydro power of between 5- 6 percent of its total grid electricity by 2030. Pakistan is situated in the tropical region and is fitted with plentiful, permanent renewable energy resources (including solar, wind and biomass). The use of these services is most suitable for decentralized energy needs in rural areas [17].

2.3 Renewable Energy Sources in Pakistan

Pakistan has great potential for renewable energy resources, but up to now this potential has been exploited by only a few solar and wind projects and huge hydroelectric projects [18]–[22]. The current installation of solar PV, wind and biomass power projects accounts for 1136 MW of renewable energy. There are also opportunities to encourage wind, solar and biomass projects [23].

Previously, the Pakistan Government (GoP) had announced many different policies and environments for enabling the enterprise to invest in the renewable energy sector, including feed-in tariff/upfront tariffs, tax incentives, net calculation, long-term refinancing facilities and micro-financing systems [20].Taking into account demand growth, technological advances, recent cost reductions and new financial structures, the GoP has agreed to open the market and to promote more competition for RE electricity supply (e.g. wind and solar) among private players at optimal rates.

Consequently, the Government has submitted offers for the RE power projects, calling for competitive/reverse bids, and a first phase of bidding is started [20].

2.3.1 Wind Energy

Wind energy is generated using wind power through wind turbines. This energy is one of the best and cleanest energies. Worldwide electricity consumption has 1.31% of wind energy which is used by countries like Denmark, Portugal, Spain, Republic of Ireland and Germany with the usage rate of 19%, 9% and 6% respectively [24][25].

Specifically, in Pakistan, in coastal Balochistan, Pakistan is potential for wind power. At some locations in the Keti Bandar - Gharo corridor, the wind speed is on average 8.1 m/s.

The technological potential of wind power along the 1.000 km of coastline, where wind speeds vary between 5.2 and 7 m/s, is high, especially in the southern regions of Sindh and Balochistan [26]–[28]. The potential wind energy capacity is estimated at 122.61 GW/year, more than twice the current level of power generation in the region. One of a series in Pakistan to reduce the country's extreme energy deficit is a wind farm newly completed in Gharo, Sindh province [29][30].

2.3.2 Biomass

Biomass energy is produced by agricultural waste and animal waste. Being an agricultural country, Pakistan produces a significant amount of biomass in dry waste form i.e. twigs, fuel wood, agro waste etc. and wet waste in the form of bagasse sugarcane, organic effluent materials, cattle dung etc [31]–[35].

21.2 million hectares are planted, of a total area of 79,6 million hectares; almost 80 percent is irrigated. The nation has the biggest adjacent irrigation system in the world. Forests occupy 4.21 million hectares, 5% of the total area of Pakistan. This has been down steadily since the 1990s to just 1.9% in 2015, according to FAO results [36].

"In Pakistan, there is also widespread biomass availability. Around 50,000 tons, 225,000 tonnes and over 1 million tonnes of animal manure are produced daily in the area of solid waste. Potential biogas output for livestock residues is estimated at between 8.8 billion and 17.2 billion meters3 (equivalent to 55 and 106 TWh of energy) per year. Pakistan's large sugar industry also produces biomass power for use in sugar mills. Annual bagasse power production is forecast at 5,700 GWh – about 6 per cent of the current level of Pakistan's power generation [37].

2.3.3 Hydropower

Hydropower is produced by rotating the water in high speed that generates electricity. Hydro power resources with low electricity consumption are categorized as small, mini and micro with generation of less than 25MW, 1MW and 100KW respectively [38]–[42].

The large Hydro power has been proven to be the most economic electricity source. Low investments in this sector impede the use of this potential source, despite the high availability of hydropower resources.

The country has smaller sites (less than 50 MW) available. There is still reasonably good business in the micro-hydroelectric market. Since the mid 80's, some 40,000 rural families have been supplying electricity from hydro-micropower plants. Most of the plants are found in the northern areas of Chitral. Another interesting solution for off-grid electricity generation is Small Hydropower. In 2016, 128 MW were in the country, 877 MW are being installed and about 1500 MW are available for further growth, and the provincial governments are mainly handling the small hydro-power sector. The micro hydro potentials in Punjab (up to 100 kW) and Northern Pakistan (up to 300 MW) are estimated [9].

2.3.4 Solar Power

It is estimated that the solar capacity is over 100,000 MW. The solar capacity of Pakistan is high. There are around 5.51-6.0 kWh/m2/day of radiation throughout the region[43], [44] [45].

Solar Village Electrification: More than 40,000 villages that are so far from the grid that it costs money and is futile to expand the grid to these sites are primary candidates for the use of Solar Home Systems (SHS).

Solar water heaters and geothermal heat pumps: Investors in the domestic and industrial sectors have a wide demand for SWH and GHP. The natural gas piped is accessible only to 22 percent of the population.

Productive agriculture uses: the 260,000 water pumps (tubing-pump), with the power supply of more than 2 500 MW, and the other 850,000 diesel water pumps which consume 72,000 tonnes of diesel per annum could have been replaced by the Solar-Powered Efficient Pumps. Streetlights: Pakistan offers more than 400 MW of licenced Street Lights. The majority of these streetlights are centred on sodium lights 80W, 125W and 250W. They have possibilities for efficient solar lighting to be replaced [6].

2.4 Solar- The center stage of renewable energy

The radiant heat and light energy produced by the Sun is referred as solar energy and one of the most abundant and simplest source of energy [46]–[48]. using a variety of inventions and continuously changing technologies since ancient times, this energy has been harnessed by people. The planet receives more energy in just an hour than is consumed over one year throughout the world [1].

The nuclear fusion reaction is the process that is responsible for the production of solar energy. In this reaction with matter loss, four hydrogen atoms form one helium atom. This is radiant energy that is released. Pakistan is in abundant and long days a tropical country with sunshine. There are about 301 bright sunny days in one year.

On average, the incident in Pakistan, solar energy varies between 3.1 and 7 kWh/m2 a day. Sunshine is available at 2,301-2700 hours a year, depending on the venue[49]. That is far more than the current consumption of total energy. With a 15% conversion efficiency for PV modules, for example, the projected electricity demand in Pakistan will be a thousand times higher by the year 2020 [1].

Solar energy is used for various purposes by different technologies including industrial applications, heating processes, cooling storages, water treatment (distillation and disinsertion), timber seasoning, cooking and drying.

Sunlight is directly transformed into electricity using photovoltaic cell, or photovoltaic is also used to directly produce electricity by the use of solar or CSP concentrations. Solar radiation is directly converted to DC power by photovoltaic. In areas such as indoor or household illumination, street lighting, rural or village-level electrification [50], water pumping[51], salty water desalination[52], remote telephone repeating stations[53], railway signals[54], etc. photovoltaic can use a variety of different applications.

2.5 Advantages of Solar Energy Systems

2.5.1 Environmentally friendly

- Solar energy is a renewable energy form that allows our environment to be safe, clean and sustainable.
- It does not contribute to emissions by released into the atmosphere like certain traditional sources of energy, such as sulphur dioxide, mercury, carbon dioxide and nitrogen oxide.
- Thus, solar energy is not responsible for smog, acid rain or global warming.
- It contributes aggressively to reducing toxic emissions of greenhouse gases.

- Since no fuel is consumed by solar electricity, it does not raise costs nor contribute to transportation or fuel recovery issues, nor does it add to storage and disposal of nuclear waste.
- Saves money.
- After the recovery of the initial investment sun's energy is virtually FREE.
- Depending on household energy use the reimbursement period for an expenditure can be low.
- Financial incentives are offered by the government to reduce the cost.
- The extra energy your device generates can be purchased by your utilities to generate your credit on your account. This is referred to as net calculation.
- The supply and demand of fuel is non-impacted, and thus the prices of petrol are not continually rising.

2.5.2 Independent/ semi-dependent

Solar power can be used to offset energy consumption given by power. It not only lowers the energy bill but provides power to our company/home if a power failure occurs. These systems can work independently, without any gas or power grid connection. They are therefore more realistic and cost-effective than having power supplies at a remote and new site in remote areas such as the holiday log cabins[55]–[58]. Solar Energy increases opportunities for local jobs and the production of resources and thus contributes to local economies.

2.5.3 Low maintenance

- Once installed, solar energy systems last ten years and are virtually maintenance-free.
- No recurring costs will arise once installed.
- They are not moving pieces, they do not make noise, they do not emit unpleasant smells and they do not need fuel

2.6 Solar Photovoltaic

Solar photovoltaics is the mechanism by which a solar cell is converted (sunshine) into energy. The solar cell (a silicon or other material semi-conducting unit), when exposed to the sunlight produces electricity. The magnitude of the produced electrical current depends upon the ambient temperature, the type of material used for the solar cell manufacture and the strength and exposure of the solar cell. Solar cells are connected to modules that provide the necessary power in series and parallel combinations[59], [60].

2.6.1 Photovoltaic module

Photovoltaic (PV) modules are commonly composed of solar cell strings made from crystalline silicon [61], [62]. These cells are very thin (about 300 um) silicon wafers which is extremely vulnerable. A cell line is hermetically wrapped among ethyl vinyl acetate (EVA) and the toughened glass layers in order to protect the cells from injury. Under the EVA layers, an isolating tedlar layer provides additional security for the cell string. The strength is provided to the module by attaching an external frame and make the frameworks simple to install. The rear of a module is fitted with a terminal box; here the terminals are soldered or welded by two ends of the solar line (positive and negative). This whole module is a PV module. When the PV module is in use the terminals are either linked to a load or to a separate array module. Different power can be produced by single PV capacity modules. A photovoltaic array of many parallel and/or series connected modules is used for large power applications[63].

2.7 Applications of Solar Photovoltaic

2.7.1 Photovoltaic Lighting Systems

The photovoltaic lighting systems are becoming common in both parts of the country i.e. urban and rural. photovoltaic luminaire systems are used in rural areas as portable lanterns, housing lights with one or more fixed lights and street lighting systems. In urban areas, implementations include road sign display systems, traffic signaling systems, LED-based message display systems, and advertising hoarding systems[64].

Figure 2.1 PV Road Lights [65]

A standard road lighting system includes an 11 W CFL, a 75 AH capacity, a flooded 12 V lead-acid battery and a 74 Wp capacity photovoltaic module. This method can be used from dawn till dawn (that is, all night long) [66]. When the world is dark and turns off around the sunrise time the CFL automatically illuminates. SLS costs roughly Rs 19 000. The ministry provides funding for the promotion among qualified categories of users of some of the above solar lighting systems.

2.7.2 Photovoltaic power plants

Electricity is produced centrally in a photovoltaic power plant. This electricity is delivered to the users either in "grid-interactive" mode connected to a traditional grid or in "stand-alone" mode via a local grid. To meet lighting and other requirements, independent energy plants locally provide people with grid- quality power. Power costs can be in the range of Rs 15 per kWh for an independent plant and for a grid-interactive power plant [67]–[69].

Figure 2.2 PV Power Plant [70]

2.7.3 Solar Generators

A compact, stand-alone solar generator power system is composed of a PV panel that is attached to a properly sized inverter and a battery bank. This power system is intended in circumstances such as traditional power loss or load shedding to provide energy to minimal load (i.e. fans and lights) for the duration of 2-3 hours a day. The MNES now promotes four versions of solar energy generators i.e. 150, 350, 450, and 600 Wp. These solar power generators are primarily intended to replace traditional small-scale oil-based power generators used by shops, clinics and other small businesses during regular load shedding cycles in urban regions. The elements of a standard sun generator are a tiny photovoltaic module that connects the required battery bank to an inverter on 12, 24 or 48 V power supply, for 2-3 hours, for power supplies for loads including lamps, fans, credit card and personal computers. The costs of the MNES four solar generator models differ between Rs 35,000 and Rs 1,45,000.

2.7.4 Building-integrated PV Systems

PV panels are installed on the front or into the building rooftop with a built-in photovoltaic (BIPV) system. In Europe, the United States and Japan, BIPV systems are becoming popular. During the day the photovoltaic panels produce electricity that is used to fulfil part of the building's electricity needs. BIPV systems in Pakistan have great potential, with a huge number of constructions being designed each year for various ideas and a rapid rise in the energy consumption in buildings. Although the initial cost of a BIPV system is high, a decrease in electricity usage results in long-term savings. Pakistan needs more BIPV technology expertise. The BIPV projects are supported by Ministry and the buildings constructed by semi-government and government sector are financially supported by meeting 80 percent of the cost of PV modules for built in systems to facilitate this application and prepare producers and users [71], [72].

2.7.5 Photovoltaic Pumping System

One of the most significant PV applications in Pakistan is water pumping. A photovoltaic water pump operated by the photovoltaic system which can be floating, submersible or surface-mounted and is an AC or DC pump. The array is mounted on an acceptable structure with its modules positioned in shadow free surface, inclined at local latitude and south-facing. Typical photovoltaic water pumping system is a 200-3000 Wp photovoltaic array that is mounted on a structure style tracking/untracking. The array is linked with a corresponding capacity DC or AC pump which may be surface-assembled, submersible or floating. The rest of the system consists of interconnecting cables and electronics. photovoltaic water pumps are used for irrigation and drinking water drawing [73], [74].

2.8 Photovoltaic System

A photovoltaic system (PV) consists of one or more solar panels in combination with an inverter and other electric and mechanical hardware that generates electricity using sun power [1]. The scale of PV systems varies widely from smaller rooftops to compact systems to large utilities. PV systems can act as off-grid PV systems alone; however, the study is focusing on utilities grid-connected systems or on PV systems connected to a grid [2].

How do these Systems Work?

The light from the sun consisting of energy paquets known as photons falls into a panel and in a mechanism called the photovoltaic effect, produces an electric current [3]. Each panel produces relatively little energy but can be combined to generate higher energy amounts as a solar panel with other panels. Strom created from a solar column (or panel) is in direct current form commonly known as (DC). Although numerously electronic equipment uses DC electricity [4], like your phone or laptop, the electrical grid that provides (and needs) alternate electricity (AC) is built to work. Therefore, the electricity is converted from direct current to alternate current using an inverter to make Solar Power useful. The inverter AC electricity can then be used locally to power electronics or sent to the electricity grid for other use [5].

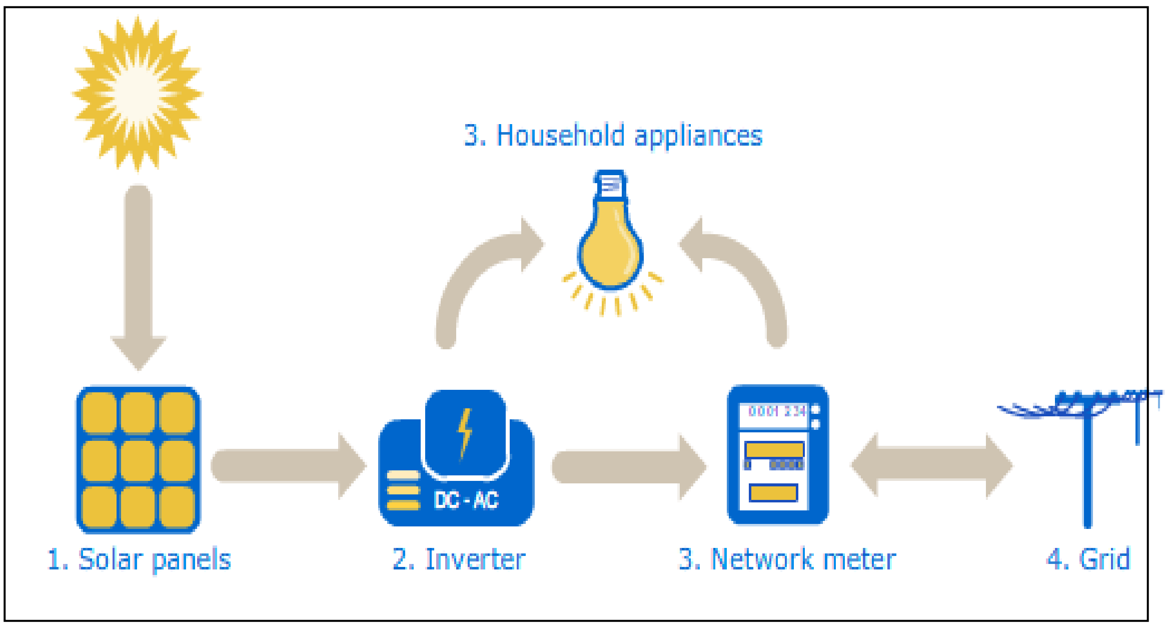

Figure 2.3 layout of On-grid Solar Power Station

2.8.1 System Components

Other essential photovoltaic system elements, generally referred to as "balance of system or BOS", exist in addition to solar panels. Inverters, racking, cabling, combinators, disconnectors, circuit breakers and electrical meters are all part of these components (typically covers almost the overall cost of maintenance and partial cost of the system) [6].

2.8.2 Solar Panel

A solar panel consists of several solar cells with semiconductor characteristics encapsulated in a material for environmental protection [7]. With the help of these characteristics, the light is absorbed by the cell or photovoltaic effects occur precisely which transforms its energy into useful electricity. The energy produced is collected through a layer of conducting material that can be found on either side of the semiconductor. The panel has an illuminated side that contains a reflective-resistant cover, to reduce reflection losses [8].

Figure 2.4 Solar Panel [9]

Crystalline silicon is found to be best for solar panels and almost more than half of the solar panels manufactured throughout the world are made from this material because for electricity conversion a limit of 33 percent theoretical efficiency is given by crystalline silicon [10]. Many additional semiconductor materials and technology from solar cells have been produced with higher efficiencies, but with greater production costs.

2.8.2.1 Inverter

An inverter is a device that receives direct current (DC) and then transform it into alternating current commonly known as AC. This means that the Solar Array DC current is fed to an inverter that transforms it into alternating current (AC) for systems that provide solar energy. This transformation is needed for most electrical devices or for an electrical grid interface [11]. Inverters are generally the most expensive components for almost all solar energy systems following the solar panels.

Figure 2.5 Solar Inverter mounted to Racking of Panel [12]

Most inverters have 90 percent or higher conversion efficiency and have significant safety features such as ground failure disturbance and anti-insulation. When grid power is lost, they shut down the PV system.

2.8.2.2 Racking

Racking is the holding device used by technicians that holds the solar panels/plates to the roof or to the ground. These devices are usually made of steel or aluminium and repair the solar panels with a high precise precision in place mechanically. Racking systems are intended to withstand extreme weather conditions, such as heavy snow accumulations, tornadoes/twisters and wind speed of hurricanes. Another significant characteristic of the racking device to avoid electrocution is the electrical relation and bonding of the solar array [13].

Rooftop racking systems are usually available in two different variations in order to provide easiness during installation i.e. pitched and flat. For roofs that are flat, gravity is considered as a managing factor and weighted ballast is usually used to hold the array. On tangled roofs mechanical installation of the racking mechanism to the roofing framework is necessary.

Both ballasting and mechanical anchors may be used to tie the range to the floor, as shown in the figure above. Certain ground mounted racking systems often integrate tracking systems that monitor the Sun through the sky with the motors and sensors and increase the energy produced on higher equipment and maintenance costs.

2.8.2.3 Other Components

A typical Solar PV system is composed of a number of components i.e. combiner, disconnects, breakers, meters and cables. A larger electric cable has two or more cables connected in it and for this purpose a cable combiner is used. Combiners are usually protective fuses that are connected with large or all medium sized solar arrays. Solar systems are designed for manual disconnections and for this purpose disconnectors are used, that are switches or electrical gates and allow the electrical wire to be disconnected manually [14]. The "DC disconnect", "AC disconnect" and electrical insulation are usually installed on both sides of an inverter and are used when an inverter is substituted or mounted on the roof.

Circuit breakers are used in solar energy systems to avoid current or spikes from electrical devices. The breakers may also be manually controlled as an external interconnection and when the current exceeds a predetermined number they are configured to automatically activate [15]. An electric meter calculates the amount of energy flowing through it and is widely used to calculate and charge consumers by electricity utilities [16]. For solar photovoltaic systems, both the incoming energy and the outgoing energy from solar photovoltaic system are measured through a bi-directional electric meter.

Finally, cables or electrical cables convey electric energy and must be properly sized to transport current from and from each part. Sunlight-exposed wiring must be shielded from UV exposure, and wires with a DC stream often need additional shielding from metal sheathing [17].

2.8.3 Positioning of the panels

The position of the solar panel is a very important and influencing factor for the energy generation [18]. The output energy produced by a solar panel depends on the amount of sunlight (that can be high or low depending on position) consumed by the panel daily. Some solar panels are constantly monitoring the sun, but most of them are not going to be costly or difficult.

We have to ensure that the panels are reached by as much light as possible. This takes place when the panel faces the sun directly

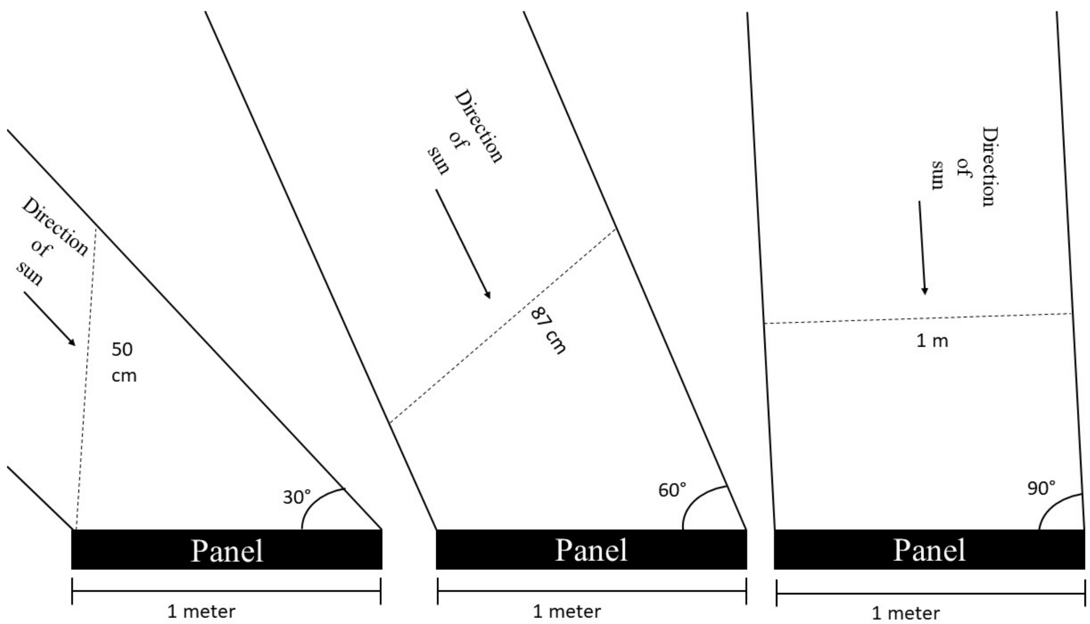

Figure 2.6 Radiations at Different times of a day

The angle of the sun reaching a panel, as you can see from above, affects exposure. At 30 degrees from the wall, only 50% of the light is exposed to the Sun, 60 degrees, 87% and 90 degrees, 100%. In a cm^2 similar number of photons are emitted by sun but once the panels are installed on any of the given angles, they scatter over a wider region [19].

The sun passes across the sky at various times of the day and thus any stationary panel becomes exposed to various angles, so at one time of the day that which is above directly is not next. It is not always straight up, but could be off by an angle, if the sun is the highest you are uncertain. This angle changes at different latitudes and different time zones. This angle is achievable at the south of the southern hemisphere and the north of the globe [20].

2.9 Solar Energy in Balochistan

Balochistan is one of the four provinces of Pakistan and is located in the South region mostly covered with desert and mountains. Due to this very reason this region is very rich in the resources of renewable energy that are to be explored by the Province's sustainable growth. Photovoltaic technology is particularly suitable for limited power requirements and remote areas. The largest province of Pakistan is Balochistan but the residents are still very poor. The villages and rural areas have a greater population, which is 77%. These towns are divided by great distances and are not readily accessible by road. Many homes in villages have limited electricity demands ranging from 50100 W. It is not economically viable to relay power lines in small towns except for very low power requirements. In the case of electricity, primarily for lighting and fans or cell phone recharging, the use of renewable energy can be easily accomplished [75].

The average annual daily radiation from the solar system is 5.9-6.2 $kWh/m^2/day$ in the Balochistan compared with the rest of Pakistan. The rising demand for energy means that Baluchistan's solar energy potential needs to be completely exploited. Solar energy is a reliable source of renewable energy, which is readily available. The average sunshine period for the province is 8-8,5 hours per annum with a mean global daily insolation of 19-20 $MJ/m^2/day$. The areas with the highest solar irradiation are suitable for photovoltaic (PV) systems and solar concentrate (CSP). These are among the world's highest solar power potentials.

A solar power plant with a capacity of 300MW has been signed for Quetta with CK Solar Korea. The GoB is allocating 1500 acres to this solar power plant project near Kuchlak, District Quetta. However, updates on the project were not yet available in December 2014 and were due to be done in 2017.xv Certain ventures in solar PV Balochistan are mentioned in Table2.2.

Table 2.2 Ventures in Solar PV Balochistan [75 - 77]

Region	Power Generation	Rank/Status
Kuchlak, District Quetta	300 MW	MoU signed
Tehsil Jaffarabad	7.9 kW	Operational
Tehsil Zahri, District Khuzdar	10 kW	Operational
Hospital electrification, District Mastung	14.5 kW	In progress
Rural electrification, Tehsil Kalat	41.1 kW	In progress

2.10 Power Status of Balochistan

Balochistan has been deprived of adequate access to electricity despite of being rich in sources of energy like renewable energy, gas, oil and coal. During the course of different studies three main reasons were observed in the area for poor electrification. First, about 91% of villages are non-electrified and the provincial residents of about 85.1% live in rural areas. The non-electrified villages are in remote areas and dispersed over huge lands due to which it is inefficient and expensive to connect these areas with the grid. Second, in rural areas varying from 52 to 100 W, the electrical energy call for houses is very short. In such areas the only condition of houses is only lighting because the rooftops and walls of houses are built of hay with mud which are usually one roomed. Therefore, it is an expensive proposition to install transmission lines for such a minor load. Likewise, an economic alternative in the form of generators is not acceptable because it is costly to transfer fuel to such barren lands. Third reason is, due to inaccessibility of area-specific energy-related data, lack of infrastructural services available and inaccessibility in rural Balochistan, the investors are unwilling to invest [76].

Given these factors, as the province receives large amounts of solar irradiance on its vast lands in the rural areas of Balochistan for off-grid power generation solar energy represents the best opportunity. Solar energy assessment of Pakistan was reported by the World Bank which concluded that the entire Balochistan has the highest average sunshine hours and is rich in solar energy in the world. It was also observed during the study that the most desirable peak direct normal irradiance (DNI) value of 2700 kWh/m2 for solar energy generation is achievable in the northern parts of the province. Moreover, the comparison was made in between Balochistan and Sinai Peninsula which is considered to be the best location in the world for receiving top solar radiance. Likewise, it was also suggested by Sustainability Advocacy that, due to the high temperature in Pakistan the best choice for electrification is solar photovoltaic (PV). Similarly, in order to empower the socio-economic condition of Balochistan's rural population Sustainability Advocacy argued that giving a solar panel to each house instead of extending grid lines to remote areas is a more economic approach [5].

Moreover, to electrifying the remote areas in Pakistan the only solution is off-grid power which is also concluded by the Asian Development Bank. The study is based on the radiation of Quetta and Khuzdar which is not among the rural area of Balochistan, but it will provide us a model of energy evaluation and economic assessment. Moreover, the investors that are interested in investment in Balochistan mostly staying in the Quetta region as Quetta is the capital of Balochistan [77].

The supply of electricity in Balochistan is limited to 400 to 600 MW but the current electricity demand is approximately 1650 MW. In urban areas power outages of 10–12 h is resulted by the immense shortage of electricity. In rural areas the condition of power outages is more than worse, where electricity is only available for 3–4 h in a day and around 13.16 million people that sums up to 85% of total population of Balochistan reside in these areas [78]. Most villages are small and have a population of around 100 people and consist of 20 houses [5].

It was reported by Quetta Electric Supply Company (QESCO) in the fiscal year of 2014-2015 that —"the only company supplying electricity in the province—the demand for electricity is expected to increase by 8%, reaching 2500 MW, at the end of 2019" [79].

Summary

Practice, prospects and challenges and the collect primary data about electricity price by survey, and secondary data based on the available literature and studies. According to the survey data,7% of people are very satisfied from the current prices of electricity in Pakistan. 18% are Slightly satisfied. The people who are neither satisfied nor unsatisfied are 21 %. 19 % are slightly dissatisfied while 35% of people in survey are very dissatisfied. Further, the Asian Development Bank believes that the off-grid power is the only solution to electrifying the remote areas in Pakistan. The study is based on the radiation of Quetta and Khuzdar which is not among the rural area of Balochistan, but it will provide us a model of energy evaluation and economic assessment. Moreover, the investors that are interested in investment in Balochistan mostly staying in the Quetta region as Quetta is the capital of Balochistan.

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CHAPTER 3

Research Methodology

This chapter will shed light on the methodology and calculations adopted for the estimation of energy generation that can be produced by solar panels.

3.1 Tilt Angle Calculations

Depending on what area of the planet you are the solar panel angle of your solar system is different. When they face the sun directly, solar panels have the highest energy production [1-3]. Depending on the time of day and the season the Sun travels over the sky and is low or high. The ideal angle is never set for this reason.

In order to hit the sun most during the day, you have to decide the direction to be taken by the panels and measure the optimum inclination angle. This will depend on:

- Where you live
- What time of the year you need the most solar energy?

Solar panels should always face true south if you are in the northern hemisphere, or true north if you are in the southern hemisphere [4].

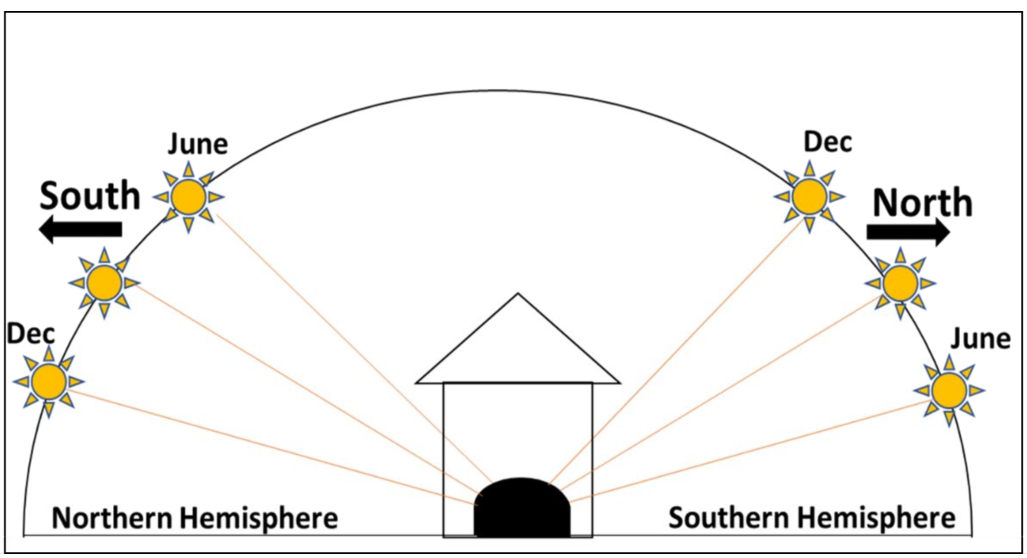


Figure 3.1 Direction & Angle of Installation [23]

3.1.1 Calculating the Optimal solar panel Angle

In order to benefit most low winter sun in summer and more tilting to optimize the production, solar panels should be more upright.

The rules of thumb in the solar sector consist of positioning the panels in the direction of the equator at an angle of inclination (equivalent to the latitude of the installation) (the angle between ground and panel) [5].

This means the panels facing south here in Quetta.

Two basic methods of measuring the latitude estimated angle of the solar panel [6].

3.1.1.1 Calculation method one

The optimum tilt angle is calculated by adding 15 degrees to your latitude during winter and subtracting 15 degrees from your latitude during summer [7].

For instance, if your latitude is 32.2°, the optimum tilt angle for your solar panels during winter will be

$32.2 + 15 = 49.2°$.

The summer optimum tilt angle on the other hand will be

$32.2 – 15 = 19.2°$.

3.1.1.2 Calculation method two

By using this method better results are calculated as this is an upgradation of the general technique used. With the help of this method, during winter season the positioning of solar panels i.e. optimum tilt angle can be calculated by "multiplying the latitude by 0.9 and then adding 29°" [8].

In order to calculate the tilt angle for the above given values then the solution will be

$(32.2 * 0.9) + 29 = 57.98°$.

Using the general method, the calculated value will be 47.98º, which is 10° flat than the new technique. By using the value 57.98º, the sunlight during the midday will enter more effectively throughout the winter season in which the middays are the hottest [9], During the summer season optimum tilt angle can be calculated by "multiplying the latitude by 0.9 and then and subtracting 23.5°"

In order to calculate the tilt angle for the above given values then the solution will be

(32.2 * 0.9) – 23.5 = 5.48°.

From the latitude, 2.5° is subtracted during fall and spring for the calculation of optimum tilt angles. North is considered 0°, east is 90°, south is 180°, and west is 270° [10].

3.1.2 Tilt adjustment twice a year

As mentioned in previous studies the tilt angle is of great value to get maximum energy from sun, so during this study we also experienced this change and adjusted the tilt of solar panels twice a year in order to observe the changes take place during electricity generation [11-12].

The important days to remember for tilt adjustment are mentioned in the table below:

Table 3.1 Tilt adjustments twice a year

Season Wise Adjustment of Tilt Angle	**Northern Region**	**Southern Region**
Tilt adjustment during summer season	End of March	End of September
Tilt adjustment during winter season	Mid of September	Mid of March

3.1.3 Adjusting the tilt four times a year

The tilt of solar panels can also be adjusted four times a year after every 3months. In order to get the maximum output from solar energy systems, the tilt must be adjusted time to time during the course of one year.

The important dates to remember for tilt adjustment are mentioned in the table below [13].

Table 3.2 Tilt adjustments 4 times a year

Season Wise Adjustment of Tilt Angle	Northern Region	Southern Region
Tilt adjustment during summer season	18th of April	18th of October
Tilt adjustment during autumn season	22nd of August	21st of February
Tilt adjustment during winter season	5th of October	6th of April
Tilt adjustment during spring season	5th of March	4th of September

3.2 Collection of radiation data

Solar radiation data was collected from authentic source of the radiation calculation devices that has been installed in Baluchistan University of Information Technology Engineering and Management Sciences Quetta (BUITEMS Quetta) by the World Bank and USAID. The data has been taken from the website energydata.info

Figure 3.2 Device to collect Radiations

Figure 3.3 Device Installed at BUITEMS Quetta

The installed device collects every 10 minutes of radiation (W/m^2) with the addition of ambient air temperature(°C), wind velocity(m/s) and humidity (%).

The header of the collected data is shown in the Table 3.3

Table 3.3: Header of the devices data [14]

Schedule	Date & time in accordance with ISO8601 standards (yyyy-mm-dd HH:MM)
ghi_pyr	Global horizontal irradiance (w/m^2) from thermopile pyranometer
ghi rsi	Global horizontal irradiance (w/m^2) from rotating shadowband irradiometer
DNI	Direct normal irradiance (w/m^2) from thermopile pyrheliometer
DHI	Diffused Horizontal irradiance (w/m^2) from thermopile pyranometer
Air Temperature	Air temperature (Ċ) at 2m height
Relative Humidity	Relative humidity (%) at 2m height
Wind Speed	Wind speed (m/s) at 10m height
Wind Speed of Gust	Max. Wind speed in integration interval
Wind from Direction standard deviation	Wind direction in degrees north, counted clockwise (standard deviation)
Wind from Direction	Wind direction in degrees north, counted clockwise
Barometric Pressure	Ambient air pressure in hpa
Sensor Cleaning	1(Yes)/0(No)

3.3 Interpretation of Data:

The devices that were installed in the mentioned place received radiation data every 10 minutes of the day. from that data we will obtain hourly data, daily data, monthly and yearly data. There are 4 types of data collected by the device [15].

- Global Horizontal Irradiance from thermopile Pyranometer (GHI) => ghi_pyr
- Global Horizontal Irradiance from rotating shadow band Iradiometre (GHI) => ghi_rsi
- Direct normal Irradiance from thermopile Pyrheliometer (DNI)
- Diffused Horizontal Irradiance from thermopile Pyranometer (DHI)

First, we converted the data of 10-minute duration to 60-minute mean one hour by taking average of 6 data column.

Then we took average of 24 data set which gave us data of 1 day and then we took average of data according to dates of the data that gave us monthly data which is discussed in the next chapter.

3.4 Technical Analysis:

We can model the PV generator according to the ambient temperature and irradiance level. Output Power of the PV Generator is obtained by using the following formula [16-18].

Here:

$$Ppv = [I_{pv} \times A_p \times GT1000 \times \{1 - \Gamma \times (T_i - 25)\}] \times \eta_P \times P_r \times N_{PVS} \times N_{PVP} \qquad (1)$$

Ppv = Power obtained from Photovoltaic Panel.

Ipv = Radiation data collected from the device $(W)/m^2$

Ap = Solar Panel Area (m^2);

GT = Standard Irradiance at STC (STC: Standard Testing Condition), GT is the standard PV reference irradiation which is 1000 W/m^2 (1000 W/m^2, 25°C and spectral irradiance distribution according to IEC60904-3)

Γ = the power temperature coefficient of module; Tj = the cell temperature.

ηp = Panel Efficiency

Pr = Performance ratio coefficient for losses (PR is taken as 80% based on the losses.) Npvs = the number of modules in series.

Npvp = the number of modules in parallel.

Performance ratio coefficient for losses is based on the following factors:

Table 3.4 Different factors that cause energy losses in Solar Farm [19-24]

Reasons/Factors of Losses	**Probability of Losses (%)**
Dust/Snow	≥ 2
Ineffective Radiation	3 ≥ 7
Temperature Drop	5 ≥ 18
Inverter Dissipation	4 ≥ 15
DC Cable Dissipation	1 ≥ 3

The solar cell temperature (Tj) can be obtained from the following equation

$$T_1 = T_{amb} + \left\{\frac{G_{T_{noct}}}{800} * (NOCT - 20)\right\} \quad (2)$$

Here:

Tamb = Ambient Air Temperature

$GTnoct$ = Standard Irradiance at NOCT (800 W/m^2)

NOCT = Nominal Operating Cell Temperature

Parameters of these equations can be obtained from information available from the manufacturer data sheets [nominal operating cell temperature (NOCT) and standard test condition (STC) [25]

3.5 Module Specification:

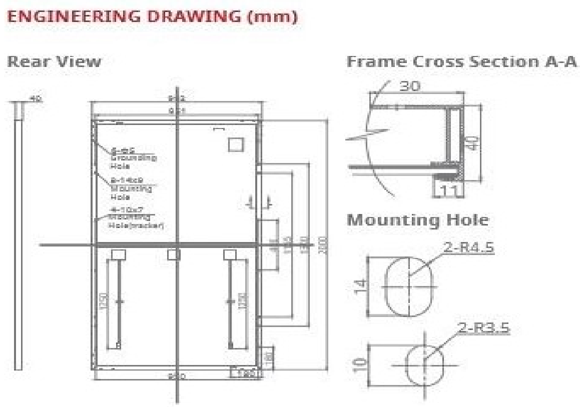
The Specification of module are obtained from the data sheet of Canadian Solar module manufacturing company [26]. Specification are given below

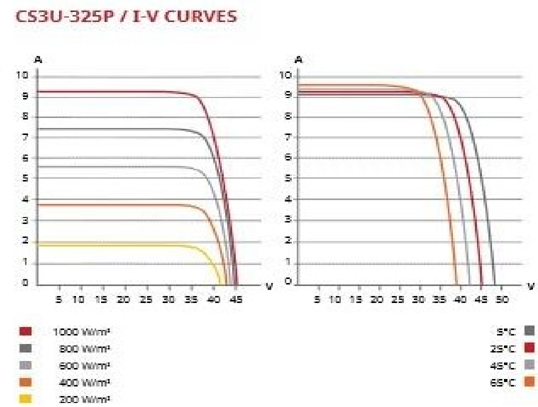
Solar panels — PV Modules

Table 3.5 Module Specifications

Module Classification	Canadian Solar CS3U-340P PV modules (Poly Crystalline)
Classification of Cell	Poly Crystalline
Volume of Individual Module	2000mm x 992mm x 40mm
Nominal Operating cell Temperature (NOCT)	43±2°C
Module Area	1.984 m^2
No. of Panel/ Modules	147,060
Total Module Area	291,768 m^2 (72.1 Acre)
Frame of Panel	Hot Dip Galvanized Steel
Power temperature coefficient (Γ)	-0.38%/°C
Module Efficiency	17.14%

The data sheet from the manufacturer are also given below





ELECTRICAL DATA | STC*

CS3U	325P	330P	335P	340P
Nominal Max. Power (Pmax)	325 W	330 W	335 W	340 W
Opt. Operating Voltage (Vmp)	37.8 V	38.0 V	38.2 V	38.4 V
Opt. Operating Current (Imp)	8.60 A	8.69 A	8.77 A	8.86 A
Open Circuit Voltage (Voc)	45.3 V	45.5 V	45.7 V	45.9 V
Short Circuit Current (Isc)	9.12 A	9.20 A	9.28 A	9.36 A
Module Efficiency	16.38%	16.63%	16.89%	17.14%
Operating Temperature	-40°C ~ +85°C			
Max. System Voltage	1500 V (IEC) or 1500 V (UL)			
Max. Series Fuse Rating	30 A			
Application Classification	Class A			
Power Tolerance	0 ~ + 5 W			

* Under Standard Test Conditions (STC) of irradiance of 1000 W/m², spectrum AM 1.5 and cell temperature of 25°C.

MECHANICAL DATA

Specification	Data
Cell Type	Poly-crystalline, half 6 inch cells
Cell Arrangement	144 (24 × 6)
Dimensions	2000 × 992 × 40 mm (78.7 × 39.1 × 1.57 in)
Weight	22.4 kg (49.4 lbs)
Front Cover	3.2 mm tempered glass
Frame Material	Anodized aluminium alloy
J-Box	IP68, 3 diodes
Cable	4.0 mm² & 12 AWG ,1250 mm
Connector	T4 series or UTX or MC4 series
Per Pallet	27 pieces
Per container (40' HQ)	594 pieces

ELECTRICAL DATA | NMOT*

CS3U	325P	330P	335P	340P
Nominal Max. Power (Pmax)	237 W	240 W	244 W	248 W
Opt. Operating Voltage (Vmp)	34.5 V	34.7 V	34.9 V	35.1 V
Opt. Operating Current (Imp)	6.87 A	6.92 A	7.00 A	7.07 A
Open Circuit Voltage (Voc)	41.9 V	42.1 V	42.3 V	42.5 V
Short Circuit Current (Isc)	7.38 A	7.44 A	7.51 A	7.57 A

* Under Nominal Module Operating Temperature (NMOT), irradiance of 800 W/m², spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s.

TEMPERATURE CHARACTERISTICS

Specification	Data
Temperature Coefficient (Pmax)	-0.39 % / °C
Temperature Coefficient (Voc)	-0.31 % / °C
Temperature Coefficient (Isc)	0.053 % / °C
Nominal Module Operating Temperature	43±2 °C

Figure 3.4 Module Datasheet [26]

3.6 Inverter Specifications

The Specification of Inverter are obtained from the data sheet of Huawei inverters company. The website for data sheets is mentioned in references [27]. Specifications are given below;

Table 3.6 Inverter Specification

Type of Inverter	Huawei Sun2000-90KTL
Dimension of each Inverter	1,075 x 605 x 310 mm
No. of Inverters used	554
Max. efficiency	99%
Max. Input Voltage	1500 V
Rated AC Active Power	90,000 W

Table 3.7 Data sheet of the selected model [27]

Technical Descriptions of the Inverter	**SUN2000-90KTL-H1**
Performance	
Maximum productivity	99.0 %
European productivity	98.8%
General	
Volume (W×H×D)	1075×605×310 mm (42.3×23.8×12.2 inch)
Weight (With mounting plate)	77Kg (169.8 lbs.)
Topology	Transformers
Protection Rating	IP65
AC Connector	Waterproof PG Terminal + OT Connector
DC Connector	Amphenol UTX
Relative Humidity	0 to 100%
Max. Operating Altitude	4000 m (13123ft)
Cooling	Natural Convection
Operation Temperature Range	-25Ċ˜60Ċ (-13 F˜140F)
Input	
Number of MPP Trackers	6
Max Numbers of Inputs	12
Rated Input Voltage	1080 V
MPPT Operating Voltage Range	600 V ˜
Start Voltage	650 V
Max. Short Circuit Current per MPPT	33 A
Max. Current per MPPT	22 A
Max. Input Voltage	1500 V
Output	
Max. Total harmonic Distortion	< 3 %
Adjustable Power Factor	0.8 LG…0.8 LD

Max. Output Current	72.9 A
Rated AC Gird Frequency	50 HZ/ 60 HZ
Rated Output Current	65.0 A
Rated Output Voltage	800 Vac, 3 W + PE
Max. AC Active Power (Cos Ø)	10000 W
MAX. AC Apparent Power	100000 VA
Rated AC Active Power	90000 W
Communication	
Power Line Communication (PLC)	Available
U5B	Available
R5485	Available
Display	LED Indicators, Bluetooth
Protection	
Residual Current Monitoring Unit	Available
DC Insulation Detection	Available
AC Surge Arrester	Type II
DC Surge Arrester	Type II
PV-array String fault Monitoring	Available
DC Reverse Polarity Protection	Available
AC Over Current Protection	Available
Anti-Islanding Protection	Available
Input-Side Disconnection Device	Available

The Enertech Quetta Solar (Private) Limited and many other companies also uses the mentioned devices for their upcoming solar projects

As we can see that we have mentioned in the specifications of module and inverter that we have used are 147,060 modules and 554 units of Inverter. Number of modules + inverters were taken according to the simulation of 50 MW Solar plant in a software called PVsyst. The report of simulation is as follow

3.7 Economic Analysis

To analyze the economic feasibility of the proposed plant the LCOE (levelized cost of Electricity) is calculated by the help of cost estimation of this project.

The “LCOE” denotes the average income per unit of generated electricity that would be essential to recover the costs of construction and operating a producing plant during an expected economic life. Its unit can be Price/KWh

The equation for the levelized cost of electricity is given below [28].

$$LCOE = \frac{I + \sum_{t=1}^{n} \frac{(M_t + F_t)}{(1+r)}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \tag{3}$$

In the above equation:

I represent Capital cost,

Mt represents O&M (Operation and Maintenance) cost, Ft represents Fuel Cost,

Et represents Energy production at a given time t, r represents discount rate,

n represents lifetime of the plant = (in our case n=20)

i. Capital cost

It contains Module cost, Inverter cost, Land cost and other costs (installation, Labor cost, Transportation) etc [29].

- Module Cost: = \$0.609/Wp for cs3u-340p (340W) =\$207/unit Thus for 147,060 modules = \$30.44M

Module cost was taken from the manufacturer's website

- Inverter Cost = \$0.06775/W

For Huawei sun 2000-95ktl (90KW) = \$6098/unit for 554 unit = \$3.379 M

Like module Inverter cost was also taken from the manufacturer's website

- Land Cost = Rs.500/ft^2

For 4.35×106 ft^2 (100 $Acre$) = \$13.70 M

Land cost was estimated according to the recent prices in the Quetta region

- Other Cost = 40% of the total module cost = \$12.18 M

These costs were taken based on the literature Therefore

Capital cost (I) = module + Inverters + Land + Others

= \$30.44 M + \$3.379 M + \$13.70 M + \$12.18 M

= \$59.689 M

ii. O&M Cost

6% of total capital cost = \$0.9 M/yr.

These costs were taken based on the previous feasibility studies of the Quetta region

iii. Discount rate

(r) = 10.5498 % [30]

iv. Annual Energy generation

(E) = 91.980 GWh (taken from the results of technical analysis)

Now we have estimated the possible values of different costs that will assists us to calculated LCOE that will recover the operating and constructing of the plant in 20-year lifetime.

3.8 Validation of the economic analysis through Rescreen

RETScreen software is developed by government of Canada, which is known as Clean Energy Management Software [31]. The RETScreen can provide Detailed identification, assessment and technical analysis of financial parameters for different Renewable Energy technologies, co-generation and energy efficient projects. Some of Financial parameters which were observed and studied during the case study are Internal rate of return, payback Period, Net present, Cost-Benefit ratio and Energy production cost. Some of the Financial parameter which were assumed during the case study are:

Table 3.8 RETScreen Observed Financial Parameters

Financial Parameters	Percentage Value (%)	Cost ($)
Initial Cost	98	2,390,432,000
Solar Panels Cost	1.2	30,441,420
Inverter Cost	0.14	3,378,292
Land Cost in Square Ft	0.56	13,700,000
Misc. Cost	0.02	608,828

Table 3.9 Assumed Financial Parameters for RETScreen Simulation

Parameters	Value
Inflation Rate	2%
Discount Rate	10%
Reinvestment Rate	9%
Project life	20 Years

Summary

In this study methodology is based on the four objectives of the project that are to collect solar radiation data, to interpret solar radiation data for the assessment of energy potential, to perform energy calculation for the finding of power from solar radiation at particular location and to evaluate economic analysis for the prediction of cost of energy produce at particular location.

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CHAPTER 4

Results & Discussion

4.1 Radiation Data of Quetta

During the course of this study, initially the radiation data of Quetta city was collected in order to find out the sunlight intensity that reaches the ground. This data is of great value as it provides the foundation of solar power plant installation. It has been reported by World Bank that Baluchistan has the maximum irradiance value throughout the globe that is why it is the most appropriate place for installation of solar power plants [1].

During this study the radiation data was collected for more than 1 year and it was observed that during the months of May, June and July the Global Horizontal Irradiance from Thermopile Pyranometer (GHI-PYR) has the highest value i.e. 322.965, 333.6401 and 320.2997 W/m^2. It was also observed that the values of Global Horizontal Irradiance from Rotating Shadowband Irradiometer (GHI-RSI) has also the maximum value of 316.5496, 327.4765 and 314.6698 W/m^2 during the months of May, June and July [2].

During the months of May, June and July the air is also very hot due to the higher intensity of solar radiation i.e. 26.4889, 28.9332 and 30.5188^{o}C. The solar energy produced during these hot months is utilized as well as stored for later use.

The data that has been collected for Quetta, ranges from September 2015 to April 2017

Table 4.1 Collected Radiation data by the device

DATE & TIME	MONTH	GHI-PYR (W/m^2)	GHI-RSI (W/m^2)	DNI (W/m^2)	DHI (W/m^2)	AIR TEMP (^{o}C)
9/1/2015 16:30	September	265.1653	273.0576	296.3164	79.14861	20.51359
10/1/2015 16:30	October	216.8817	220.5368	279.8431	59.84138	18.92263

11/1/2015 16:30	November	170.4074	166.3632	247.4614	45.60208	11.55877
12/1/2015 16:30	December	153.3665	147.3975	228.4731	46.708	6.543504
1/1/2016 16:30	January	163.4107	164.171	262.0598	42.74644	8.021483
2/1/2016 16:30	February	213.635	214.1253	303.8594	52.50563	9.221288
3/1/2016 16:30	March	208.2139	209.4802	170.1275	97.44946	14.14848
4/1/2016 16:30	April	282.8057	281.0052	259.9633	96.75067	19.48438
5/1/2016 16:30	May	322.9655	316.5496	289.7073	99.72345	26.48896
6/1/2016 16:30	June	333.6401	327.4765	275.9372	115.142	28.93322
7/1/2016 16:30	July	320.2997	314.6698	237.3427	129.2564	30.51886
8/1/2016 16:30	August	305.4059	300.133	254.6539	110.7975	27.42749
9/1/2016 16:30	September	282.4132	281.1348	308.7969	75.2106	25.47762
10/1/2016 16:30	October	237.2802	239.4974	330.3356	51.60276	17.8069
11/1/2016 16:30	November	185.3401	188.0809	298.4731	43.641	11.19141

12/1/2016 16:30	December	161.3022	164.1644	279.2804	40.89848	10.34037
1/1/2017 16:30	January	140.8189	143.4911	186.9955	56.36658	5.424395
2/1/2017 16:30	February	172.6161	174.5788	206.5706	63.42078	8.079191
3/1/2017 16:30	March	228.4638	225.9313	201.319	93.76743	13.48687
4/1/2017 16:30	April	304.6699	299.7197	302.1102	86.04299	20.21451

The monthly data of Quetta can be interpreted in the graphs below, that is collected by different sensors.

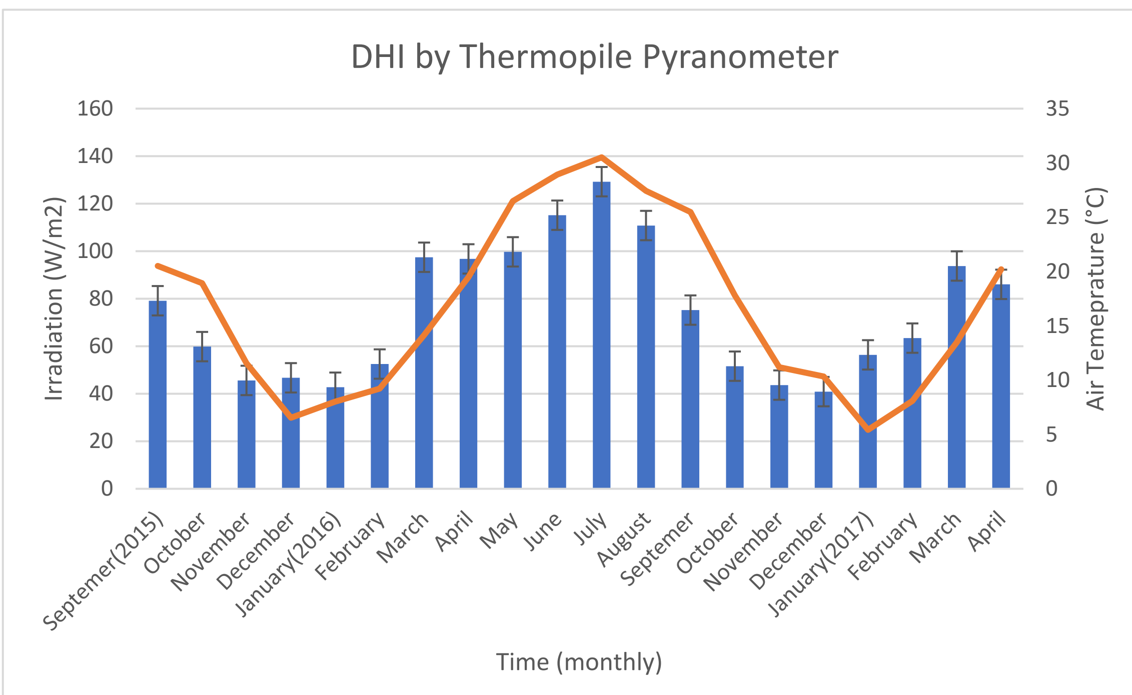

Figure 4.1 Diffused Horizontal Irradiance (W/m^2) by Thermopile Pyranometer

The irradiance of Quetta city was measured with the help of different sensors in order to knock out any error. It can be seen from fig 4.1 that when the diffused horizontal irradiance was calculated using Thermopile Pyranometer, the maximum value of irradiance was recorded during the month of July followed by the months of June and August. Similarly, the minimum irradiance was recorded during the month of January followed by the months of December and February.

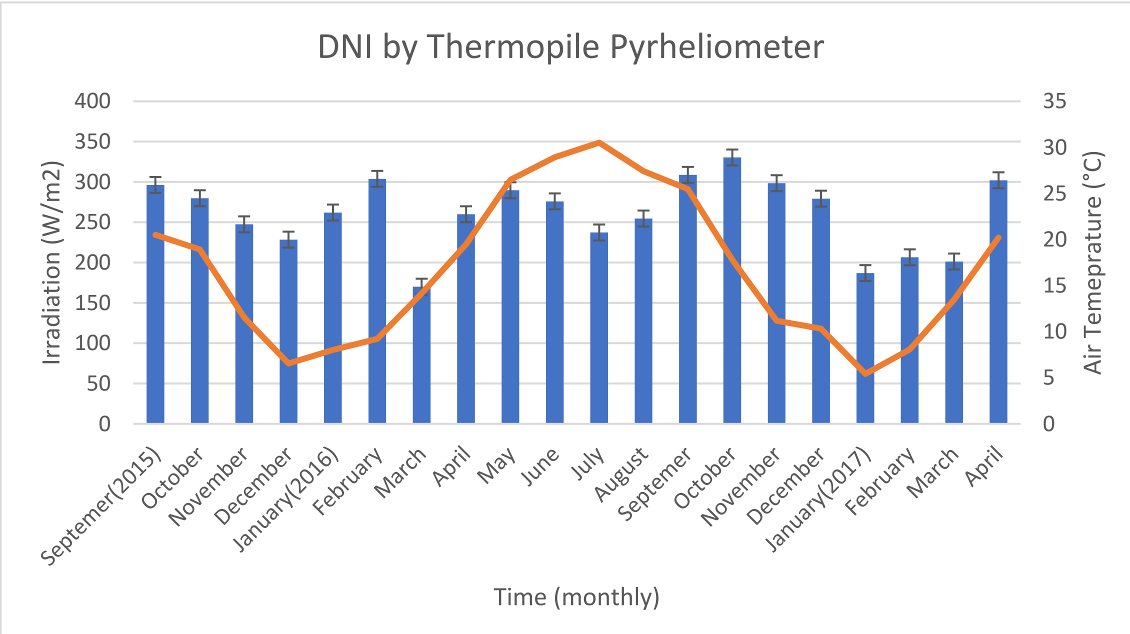

Figure 4.2 Direct Normal Irradiance (W/m^2) by Thermopile Pyrheliometer

It can be seen from fig 4.2 that when the direct normal irradiance was calculated by Thermopile Pyrheliometer, the maximum value of irradiance was recorded during the month of October followed by the months of September and November. Similarly, the minimum irradiance was recorded during the month of March followed by the months of January and February.

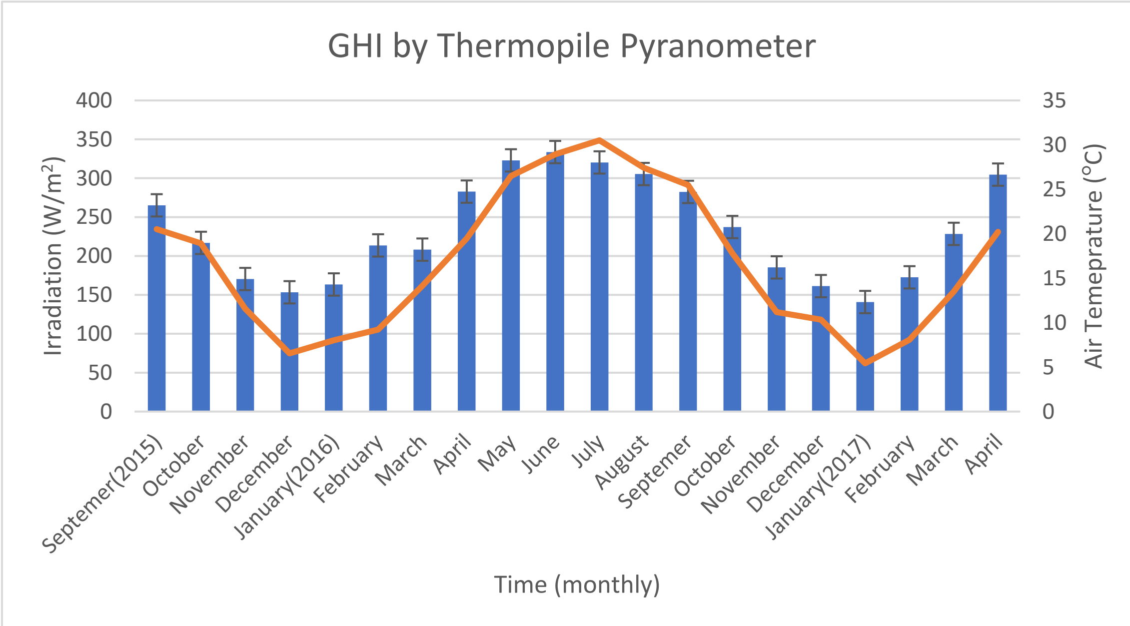

Figure 4.3 Global Horizontal Irradiance (W/m^2) by Thermopile Pyranometer

It can be seen from fig 4.3 that when the global horizontal irradiance was calculated using Thermopile Pyranometer, the maximum value of irradiance was recorded during the month of June followed by the months of May and June. Similarly, the minimum irradiance was recorded during the month of January followed by the months of December and February.

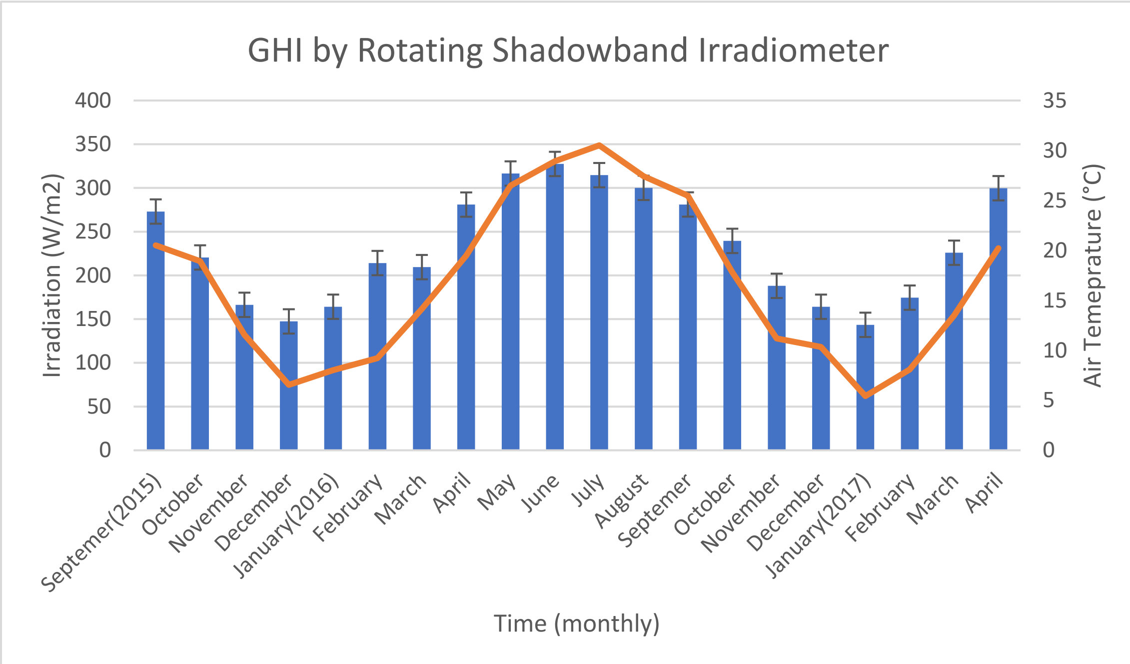

Figure 4.4 Global Horizontal Irradiance by RSI

It can be seen from fig 4.4 that, when the direct global horizontal irradiance was calculated using rotating shadowband irradiance [3], the maximum value of irradiance was recorded during the month of June followed by the months of May and June. Similarly, the minimum irradiance was recorded during the month of January followed by the months of December and February.

4.2 Technical Analysis Results

During the technical analysis it is proposed that Photovoltaic Solar Technology will be used because the phenomenon is simple and less operational cost is requires as compared to Concentrating Solar Power (CSP) and Solar Heating and Cooling Systems (SHC). The Canadian Solar CS3U-340P PV Module is proposed because it has already used in other countries and delivered excellent results. The size of each PV solar module will be 3.1m^2 as calculated from datasheet. Almost 250Acres of land is required for the installation of solar modules. As it is mentioned in the datasheet that modules have different variations as far as power is concerned. The 330Wp module is suitable with respect to cost in our proposed study. Each table has 32 modules, so one table will produce 10.56KW energy. For 50MW power plant, 8 blocks are required and each block contain 858 tables i.e. one block produces 6.25MW energy. The type of inverter is mentioned in the above datasheet that is proposed for solar plant and the capacity must be 160KW for 50MW plant is required. The losses are already added in this inverter as we considered 45% losses for such capacity of plant. The number of inverter units that will be required is 32 units.

The lifespan of PV Solar plant is up to 25 years but due to rural electrification it is proposed that this plant will be used for 20 years, after that it will be sold out in half cost to the people of tribal areas. In this case the IRR will be higher than expected and degradation process will also be taken into account. Now a day, trade has also been easier due to increased mobilization of cargos and Gwadar port made it easier for people of Baluchistan to get benefit from trade. The PV solar power plant of such big capacity will easily be taken to Quetta via Gwadar port and installation will also be easier as it will decrease the time frame of delivery.

With the installation of such a mega project there will be a significant decrease in use of fossil fuel for energy generation by QESCO. The carbon emissions because of fossil fuel pollute the environment and causes health problems in population. This project will be environmentally friendly and will contribute significantly in the decrease of carbon emissions.

$$\text{Power Production} = \text{Solar panel watt}$$

$$* \text{ average hours of sunlight } * 75\% = \text{Daily watt-hours}$$

The method for power output of solar power plant mentioned in the methodology section was followed and technical analysis was done according to their results. According to the results, the proposed plant will provide with a maximum power of 47 MW in summer months while in winter months it will provide with a minimum power of 24 MW. It can be seen in the table below that power output in different months is different according to the solar radiation data.

Table 4.2 Monthly Power Output

Months	Power Output (in MW)
January	31.12901188
February	34.78354543
March	34.85640404
April	34.26731151
May	47.7393022
June	44.62355204
July	38.34782769
August	34.11037486
September	30.60614421
October	27.5858207
November	24.09593734
December	28.20428491

As it was discussed in the chapter 3, that the intensity of solar radiations does not remain the same throughout the year because of the changing weather and rotation of Earth [4]. In Pakistan the hottest months are May and June [5, 6] so, during the course of these months the solar radiations have maximum access to the ground due to which maximum energy is produced and stored during these two months throughout the country. Within the month of May, the energy generation can reach 47.73MW followed by the month of June that will give 44.62MW. Similarly, during the winter season and cold weather, it is difficult for solar radiations to reach the ground and lowest energy will produce during the month of November i.e. 24.09MW followed by October during which only 27.58MW will be produced. The average daily output of the plant is calculated to be 36MW which can be obtained by taking three-point estimation of the calculated power in various months.

4.2.1 Three-point estimation

According to the results observed during this study the following calculations [7] will provide the end results:

Optimistic power value (O) = 47 MW Most likely power value (ML) = 24 MW Pessimistic power value (P) = 36

Thus

Estimated Power Value = $(O+4ML+P)/6$ = 36 MW

This calculated value is the average value of each day that is calculated by the values taken from the solar power plant.

4.2.2 Annual Energy Production

The annual energy production gives the exact amount of units that can be produced from a solar power plant [8]. Before calculating the annual electricity units, we must calculate the daily electricity units produced by the power plant. As the working hour of our proposed plant is 7 hrs. and the average power output is 36MW, this gives us the daily energy production or we can say average daily units of electricity.

Average Daily Energy Production = 36 MW × 7 hrs. = 252 MWh = 252000 KWh

It means the proposed plant will give 2,52,000 units of electricity to the grid daily. For the annual estimation of electricity units, we have to multiply these units by 365.

Annual Energy Production = 252000 KWh × 365 = 91.980 GWh

The following graph shows the Power output of the plant with respect to their corresponding months.

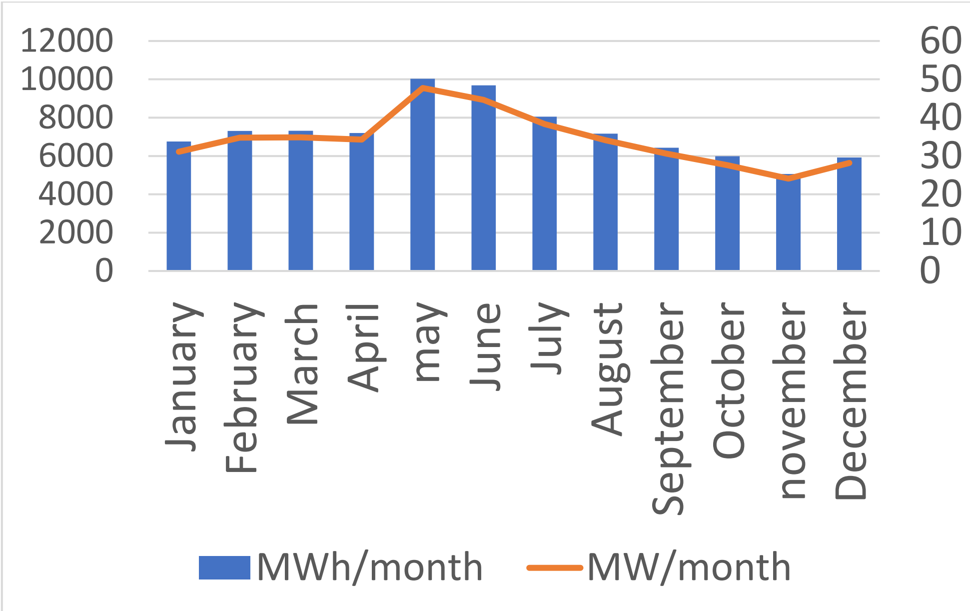

Figure 4.5 Monthly Power Output

It can be seen that during the months of May and June maximum energy will be produced by the solar power plant whereas the minimum energy will be produced during the months of October and November. It is because Baluchistan has the hottest summers in Pakistan as the temperature rises to 38ºC and during the winter season the conditions are also extreme as the temperature falls down to 0ºC during the month of December.

4.2.3 Capacity Factor

Capacity Factor (CF) defined as "It is a unit-less ratio of an actual electrical energy output over a given period of time to the maximum possible electrical energy output over that period" [9].

$$CF = \frac{actual\ energy\ output}{max.possible\ energy\ at\ rated\ capacity} \quad (4)$$

Any electrical using power plant has the measure of capacity factor that can be renewable energy i.e. solar, wind or hydro power plant or fossil fuel consuming. Different types of electricity power plants are compared with reference to their efficiency by capacity factor. The capacity factor of a power plant has efficiency lower than 100% due to the reasons that include availability of energy resource, economic reasons, technical reasons and availability of plant. The plant may be operating at low output or can be out of service due to routine maintenance or power failure.

The capacity factor of the proposed solar power plant in Quetta, Baluchistan is calculated below:

$$\text{Actual energy output} = 91.980 \times 106 \text{ KWh/yrs.}$$

Max. possible energy that could have produced at rated capacity = 50MW × 24hrs. × 365

Thus, according to the above values, we have

$$CF = 21\ \%$$

The capacity factor of the proposed solar power plant is 21% due to the several reasons i.e. availability of sunlight, cloudy weather, smog, smoke, rain and wind. These factors may cause hurdles during the sunlight hours. The capacity factor is calculated on yearly basis because of different seasons and variation of sunlight during the daytime [10]. The local cloud cover and latitude of the installation mostly determines the total amount of reachable sunlight. The electricity generated by power plant or the efficiency of capacity factor is also dependent on the factors like ambient temperature and dust. The values of these factors is inversely proportional to the efficiency of capacity factor [11].

The average capacity factor of different power plants installed is USA was calculated to be 26.1% in 2018 [12]. USA is producing energy with different sources like fossil fuel, coal, solar, wind, nuclear, hydro and geothermal. As discussed above different factors are influencing the production of electricity using solar power plant due to which researchers are working to increase the efficiency of solar power plants in order to shift the world on green energy.

Similarly, average capacity factor of solar power plants installed in UK was calculated to be 11.2% in 2019. UK is also using other sources of energy production i.e. bioenergy, marine (tidal and wave), combined cycle gas turbine stations other than solar, wind, hydro, nuclear, coal and fossil fuel.

4.3 Economic Analysis Results

The economic analysis of the proposed power plant is carried out in order to calculate the amount of per unit electricity cost that will be generated by the solar power plant [13]. As Pakistan is a developing country and the electricity production units are conventional i.e. fossil fuel based units, that is why it is necessary to analyze the pros and cons of the solar power plant. The calculated LCOE (levelized cost of electricity) of the analyzed system is calculated for their 20 years of life.

As mentioned above that for this mega project 8 blocks of 838 solar module tables will be required. The given below calculations will provide the exact cost of the project.

Price of single module (after discount of 5%) = $197.35

Number of modules required = 838 * 8 = 6704 modules

Price of overall modules required = 197.35 * 6704 = $13,18,314.6

Cost analysis of Inverters:

Price of each inverter = $7,740

Number of Inverters Required = 32 units

Price of overall units = $2,47,680

The other factors that are needed for the calculation of overall cost are:

Inflation rate of Pakistan (2021) = 8.68%

Discount Rate = 5%

Calculation of Internal Rate of Return (IRR):

$$IRR = RL + [NL/NL - NH * (RH - RL)]$$

Where;

NL = Net Present Value at Low Interest Rate

NH = Net Present Value at High Interest Rate

RH = Higher Interest Rate

RL = Lower Interest Rate

The cost of electricity for a 50 MW Photovoltaic power plant for Quetta, which has the highest sunlight reach in Pakistan, is calculated to be 0.0385 USD/kWh or 6.09 PKR/KWh. The per unit price of electricity that is being generated using the fossil fuel has the average price of 12.76 PKR/kWh. This is twice the price of electricity unit that will be generated by solar power plant. On the other hand, the energy produced by solar power plant is environmental friendly and do not harm the surroundings whereas the energy produced by fossil fuel has harmful effects on the environment [14].

The breakeven analysis of the proposed study was carried out and it was concluded that within 12 years the actual cost or payback will be possible. The unit electricity price seems to be feasible by comparing it to power purchasing price by QESCO in duration of 2019-20 [15]. This is because that extra energy produced by solar power plant is stored and can be utilized later whereas in case of fossil fuel the energy production is based on the quantity of fuel provided.

The report is presented as:

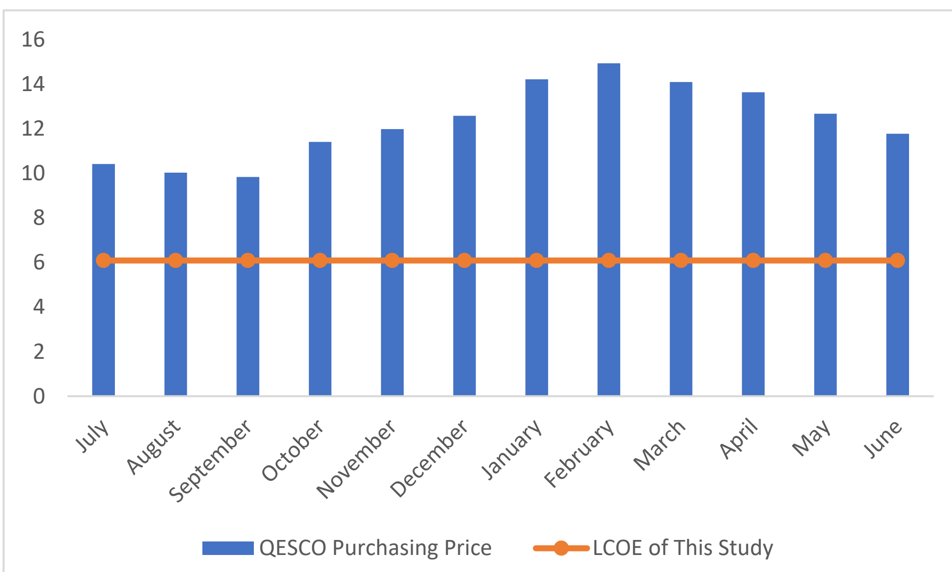

Figure 4.6 Comparison of QESCO-Power Purchase Prices with studied Solar Power Plants

The Levelized Tariff calculated in this study is 3-6 PKR cheaper than the lowest power purchasing price during the duration of 2019-20 in Quetta. This value may vary when different parts of the country are taken into account because of the positioning of the sunlight. As Sibi and Quetta are the hottest cities in Baluchistan that is why the direct sunlight generates more energy thus the levelized cost of electricity is reduced to half.

As it is mentioned in table 4.2 that the purchasing price of QESCO during the months of January, February and March will be higher as compared to other months is because during these months the energy generation from solar power plant is very less due to the winter season and unavailability of sunlight. The energy stored during the previous months will be utilized and sold as well. That is why the price is higher during these months and QESCO will be obliged to purchase electricity because of environmental pollution caused by fossil fuel plants during the winter season. The smog factor is very common in Pakistan because of air pollution caused by industries and other power plants [16].

4.4 Economic analysis through Rescreen

Different cities were simulated on RETScreen for analysing the feasibility study of 50WM Solar power plant. Moreover, different financial parameters were analysed and observed for different location in RETScreen are Quetta, Islamabad, Multan and Peshawar.

Table 4.3 Quetta 50 MW solar Power Plant Financial Parameters

Financial Viability	
Pre-tax IRR- equity	15.6%
Pre-tax MIRR -equity	11.4%
Pre-tax IRR-assets	15.6%
Pre-tax- assets	11.4%
Simple Payback	6.9 years
Equity Payback	6.4 years
Net Present value (NPV)	$ 1,085,093,193
Annual life cycle Savings	127,454,639 $/yr.
Benefit-Cost (B-C) ratio	1.4
GHG reduction Cost	-76.7 $/t$CO_2$
Energy Production Cost	0.087 $/kWh

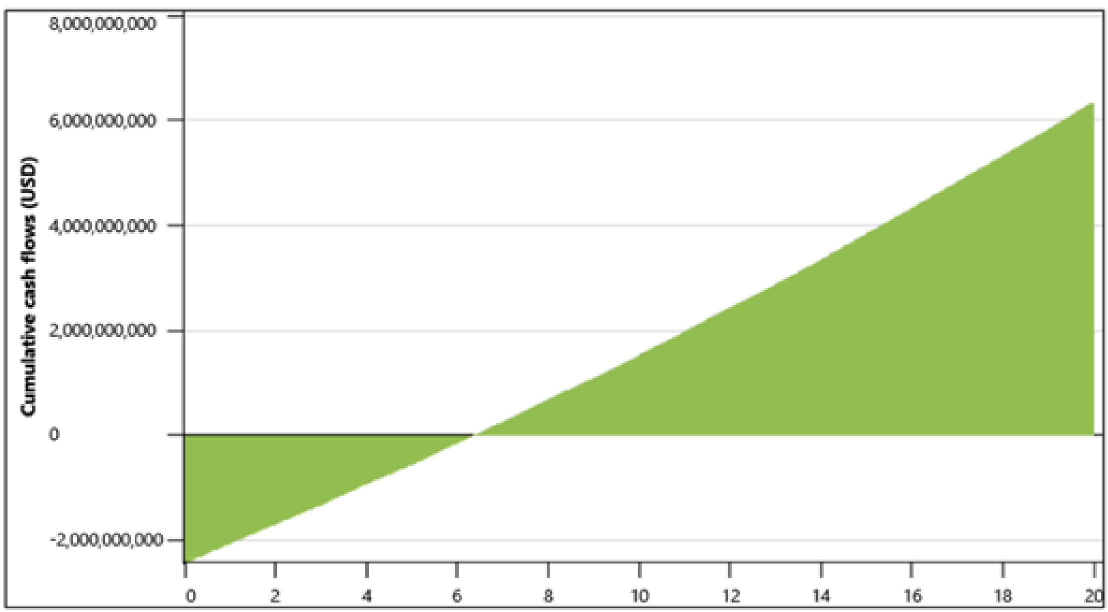

Figure 4.7 Quetta 50 MW solar Power Plant Cash Flow

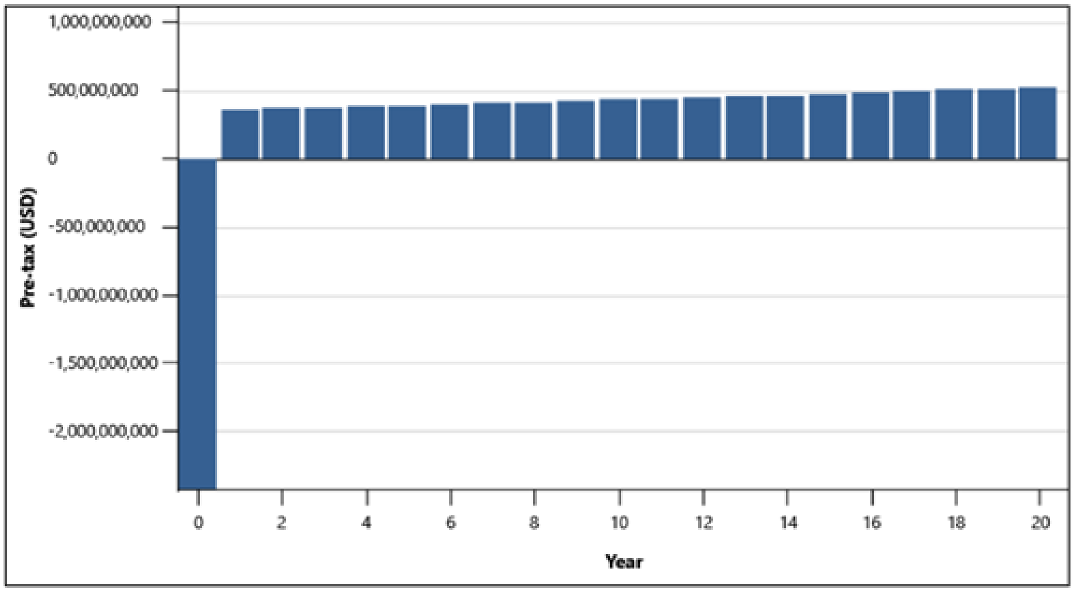

Figure 4.8 Cashflow of lifetime of Solar Power Plant at Quetta

Table 4.4 Islamabad 50 MW solar Power Plant Financial Parameters

Financial Viability	
Pre-tax IRR- equity	9%
Pre-tax MIRR -equity	9%
Pre-tax IRR-assets	9%
Pre-tax- assets	9%
Simple Payback	10.7 years
Equity Payback	9.6years
Net Present value (NPV)	$ -168,469,244
Annual life cycle Savings	-19,788,334 $/yr.
Benefit-Cost (B-C) ratio	0.93
GHG reduction Cost	17 $/tCO$_2$
Energy Production Cost	0.123 $/kWh

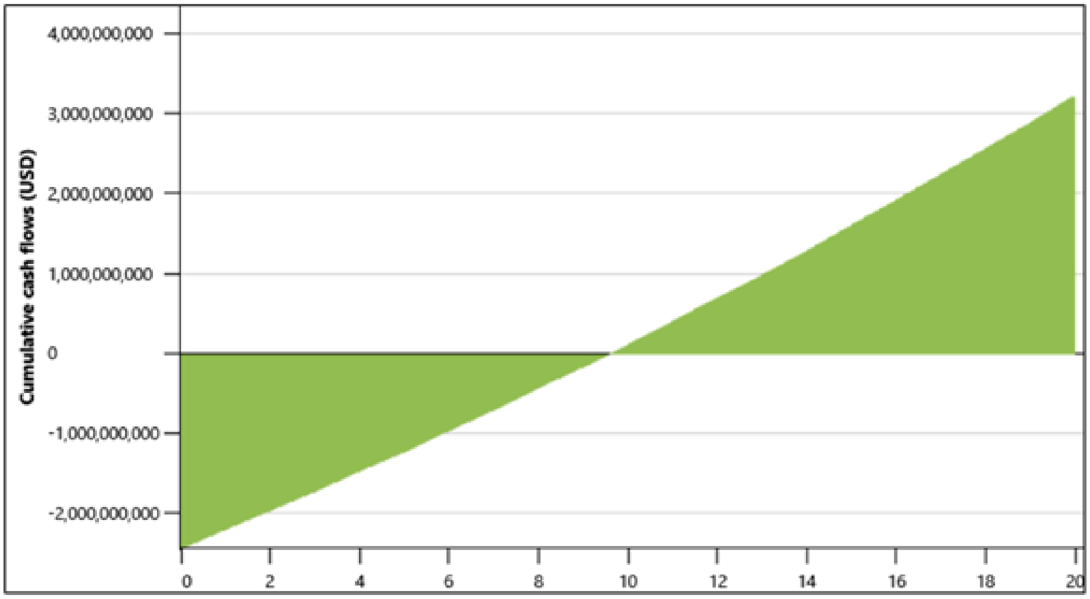

Figure 4.9 Islamabad 50 MW solar Power Plant Cash Flow

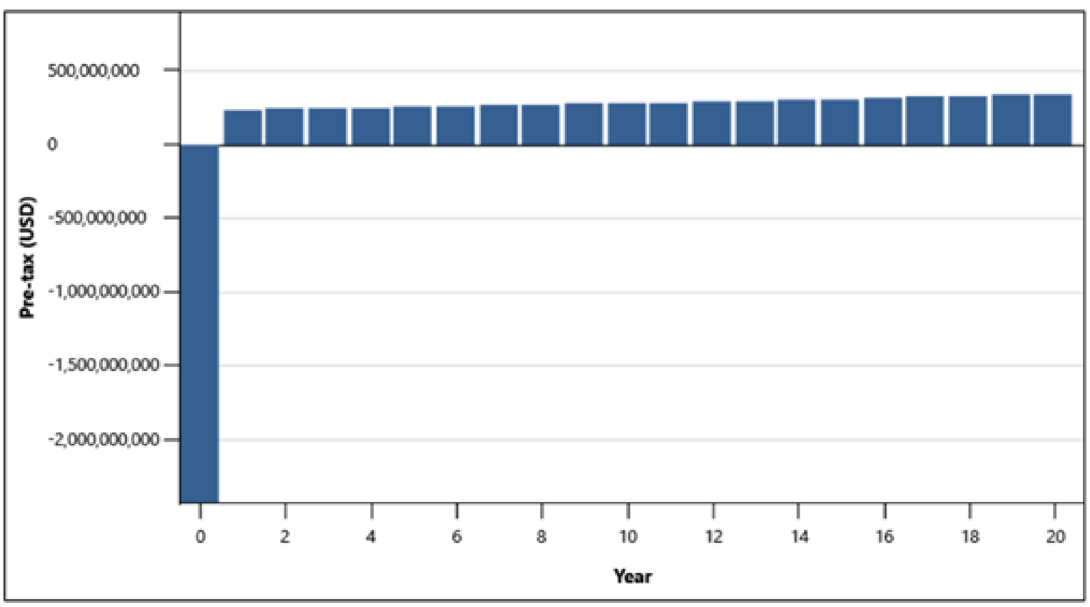

Figure 4.10 Cashflow of lifetime of Solar Power Plant at Islamabad

Table 4.5 Multan 50 MW solar Power Plant Financial Parameters

Financial Viability	
Pre-tax IRR- equity	13.2%
Pre-tax MIRR -equity	10.6%
Pre-tax IRR-assets	13.2%
Pre-tax- assets	10.6%
Simple Payback	8 years
Equity Payback	7.3 years
Net Present value (NPV)	$ 604,426,947
Annual life cycle Savings	70,995,765 $/yr.
Benefit-Cost (B-C) ratio	1.2
GHG reduction Cost	-48.3 $/t$CO_2$
Energy Production Cost	0.098 $/kWh

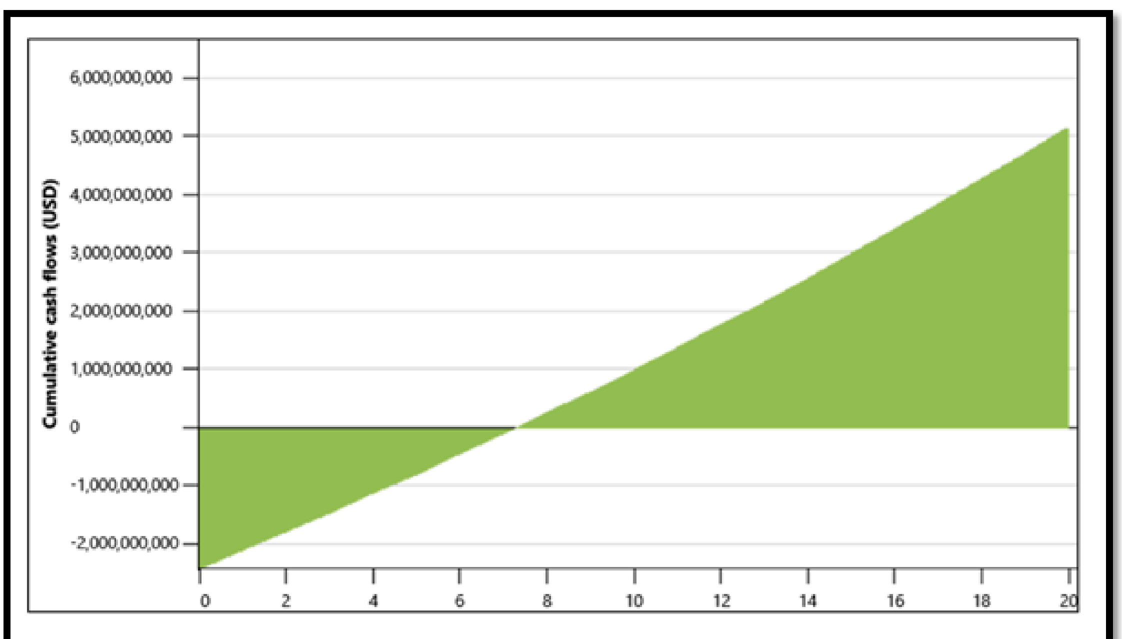

Figure 4.11 Multan 50 MW solar Power Plant Cash Flow

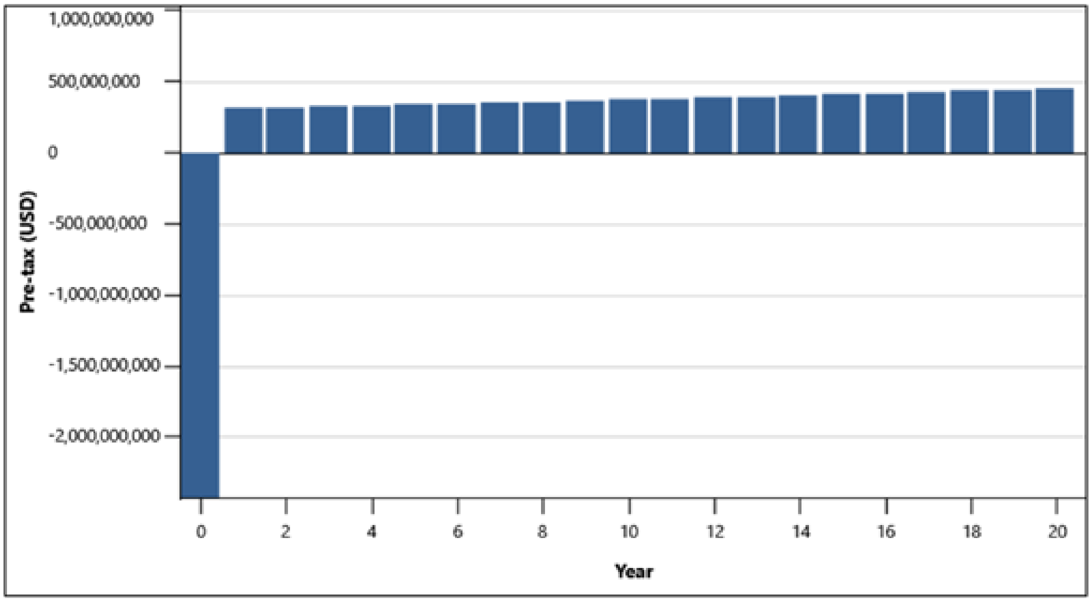

Figure 4.12 Cashflow of lifetime of Solar Power Plant at Multan

Table 4.6 Peshawar 50 MW solar Power Plant Financial Parameters

Financial Viability	
Pre-tax IRR- equity	14.5%
Pre-tax MIRR -equity	11.1%
Pre-tax IRR-assets	14.5%
Pre-tax- assets	11.1%
Simple Payback	7.4 years
Equity Payback	6.8 years
Net Present value (NPV)	$ 847,734,805
Annual life cycle Savings	99,574,612 $/yr
Benefit-Cost (B-C) ratio	1.3
GHG reduction Cost	-63.5 $/t$CO_2$
Energy Production Cost	0.092 $/kWh

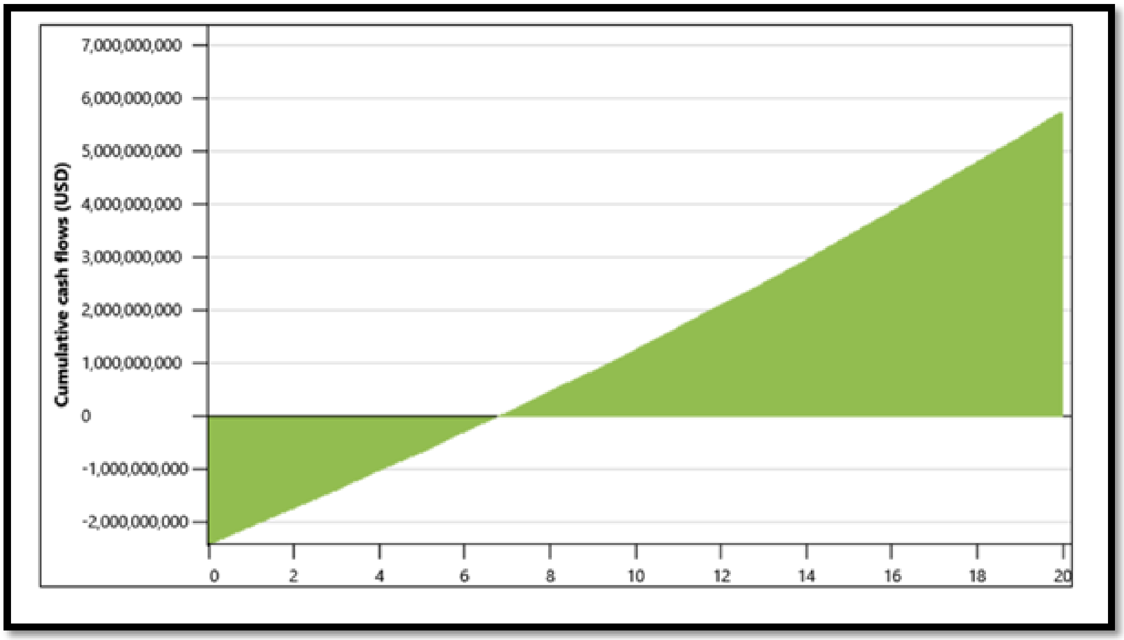

Figure 4.13 Peshawar 50 MW solar Power Plant Cash Flow

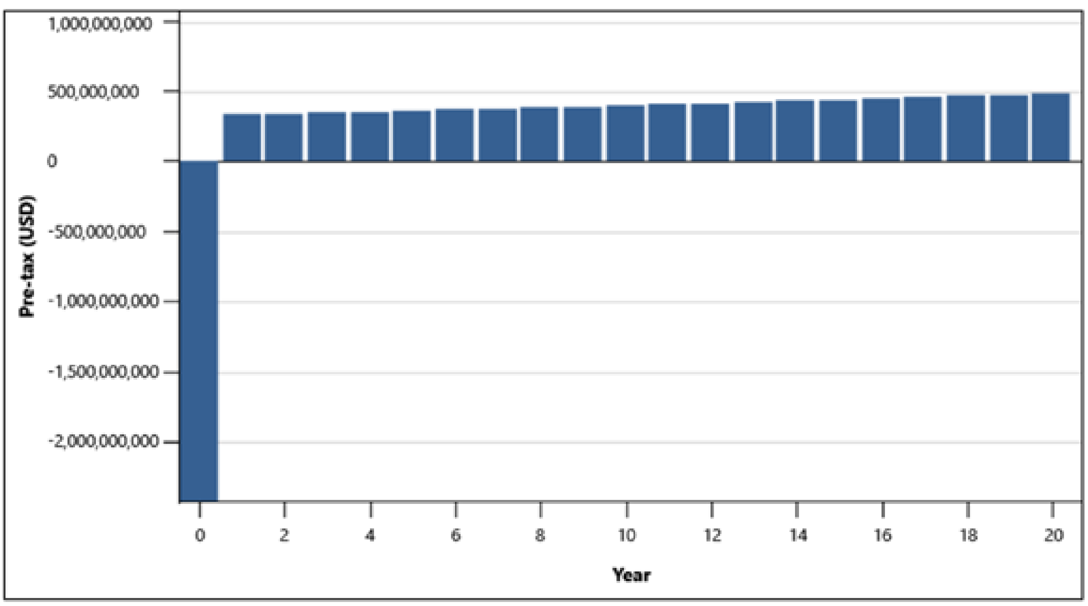

Figure 4.14 Cashflow of lifetime of Solar Power Plant at Peshawar

Table 4.7 Financial viability comparison of different cities

Financial Viability				
City	**Quetta**	**Islamabad**	**Multan**	**Peshawar**
Pre-tax IRR- equity (%)	15.6	9	13.2	14.5
Pre-tax MIRR -equity (%)	11.4	9	10.6	11.1
Pre-tax IRR-assets (%)	15.6	9	13.2	14.5
Pre-tax- assets (%)	11.4	9	10.6	11.1
Simple Payback (years)	6.9	10.7	8	7.4
Equity Payback (years)	6.4	9.6	7.3	6.8
Net Present value (NPV) ($)	1,085,093,193	-168,469,244	604,426,947	847,734,805
Annual life cycle Savings ($/yr.)	127,454,639	-19,788,334	70,995,765	99,574,612
Benefit-Cost (B-C) ratio	1.4	0.93	1.2	1.3
GHG reduction Cost ($/t$CO_2$)	-76.7	17	-48.3	-63.5
Energy Production Cost ($/kWh)	0.087	0.123	0.098	0.092

Analysis for case study of 50 MW Solar power plant was performed on RETScreen software. However, some of the financial parameters for different location were analysed to compare the feasibility of solar power plant at different locations. The four different location which were analysed are Quetta, Islamabad, Peshawar, and Multan. Quetta has comparatively cleaner atmosphere and suitable temperatures throughout the summer season for better production, although graphs from RETScreen for Quetta shows that Internal rate of return is 15.6% which convincing good, Simple Payback period for this location is 6.9 years. The simple payback period for Quetta is good as renewable energy technology. Cost to benefit ratio for project at Quetta is 1.4. Greenhouse Gas reduction in Quetta for this proposed study is -76.7 $/t$CO_2$. While the energy production cost for 50 MW in Quetta is $ 0.087 per kilowatt hours. Net present Value of project in Quetta is $ 1,085,093,193 and Annual life cycle savings of project per is about 127,454,639 [17-19].

Quetta Financial parameters shows that 50MW powerplant is beneficial for urban electrification and electricity production from renewable energy. Case study depicts that 50 MW power plant is very beneficial. It will help to provide electricity to Quetta, Bostan and near about regions, However, it will also reduce dependency of Pakistan over fossil fuel and reduce the environmental pollution. Islamabad is one of the greener cities in Pakistan, RETScreen for Islamabad shows that Internal rate of return is 9 % which is not convincing good, Simple Payback period for this location is 10 years, which higher than Quetta. Cost to benefit ratio for project in Islamabad is 0.93 [20]. Greenhouse Gas reduction in Islamabad for this proposed study is 17 \$/tCO_2. While the energy production cost for 50 MW in Islamabad is \$ 0.123 per kilowatt hours. Net present Value of project in Islamabad is \$ -168,469,244 and Annual life cycle savings of project per is about -19,788,332. Islamabad results are not as good as Quetta are, therefore, feasibility studies of 50 MW are better Quetta. Islamabad is much greener but due to higher humidity still the production of electricity from Solar energy is lower as compared to the Quetta [21].

Peshawar is one of the warmer cities of Pakistan with higher irradiance throughout the year. RETScreen for Peshawar depicts that Internal rate of return is 14.5% which convincing good, Simple Payback period for this location is 7.4 years, which is slightly higher than Quetta and lower than Islamabad location. Cost to benefit ratio for project at Peshawar is 1.3 much better than Islamabad due to better solar irradiance. Greenhouse Gas reduction in Peshawar for this proposed study is -63.5 \$/tCO_2 [22]. While the energy production cost for 50 MW in Peshawar is \$ 0.092 per kilowatt hours. Net present Value of project in Peshawar is \$ 847,734,805 and Annual life cycle savings of project per is about 99,574,612. Results from Peshawar are better as compared to Islamabad with higher production of electricity, but Quetta still has better results than Peshawar due to cleaner environment and less pollution. Peshawar is one of the polluted cities of Pakistan with low air quality index [23].

Multan is one of the Hottest cities of Pakistan with higher irradiance throughout the year. RETScreen for Multan depicts that Internal rate of return is 13.2% which convincing good, Simple Payback period for this location is 8 years, which is slightly higher than Peshawar and lower than Islamabad location. Cost to benefit ratio for project at Multan is 1.2 much better than Islamabad due to better solar irradiance and lower than Peshawar due to higher temperature. Greenhouse Gas reduction in Multan for this proposed study is -48.3 $/t$CO_2$. While the energy production cost for 50 MW in Multan is $ 0.098 per kilowatt hours [9]. Net present Value of project in Multan is $ 604,426,947 and Annual life cycle savings of project per is about 70,995,762. Multan has more irradiance than Islamabad and Peshawar but due to higher temperatures losses are higher in Multan which result in lower electricity production than Peshawar but still Higher than Islamabad. Results from Multan are better as compared to Islamabad but not convincingly good than Peshawar and Quetta. Above different parameters are discussed and analysed, it can be concluded that Quetta has most convincing and best results among these cities, despite Baran land it can be used to produce electricity from Solar energy [24].

4.4.1 Comparison of present study Levelized Cost of Energy (LCOE) with national and international photovoltaic plant studies

Table 4.2 shows the comparison of Levelized Cost of Energy (LCOE) of proposed power plant with national and international solar power plant studies. The comparison was carried out between the 9 studies around the globe that have been published and it was concluded that LCOE of 50 MW power plant in Quetta will be cheaper than the photovoltaic plants in other parts of Pakistan and international countries. The economic analysis is very important factor on which the study is based because green energy is the requirement of the world now and different initiatives have been taken by different scientific industries to utilize renewable energy sources in order to overcome the climate change crises [25].

It can be seen from table 4.2 that China has the highest LCOE value as compared to other countries but still China has shifted its power generation plants to solar energy because of the climate change [26]. China is the industrial hub and greatest manufacturing plants have been installed in China since 2004. It is also believed that the countries responsible for climate change in Asia are India and China because both countries have a large scale of industrial sector and the winds blowing throughout the region causes air pollution [27].

Different studies have also been conducted on LCOE analysis and it was observed that the energy produced by solar power plant is cheaper than other resources in Pakistan as well as other parts of the globe. Another study was carried out in which it was reported that in different rural areas of Balochistan that LCOE is 7.89 PKR.

Table 4.8 Comparison of Different Factors with National and International Studies of Solar plants

Sr.#	Location of Solar Power Plant	Capacity (KWh)	LCOE (PKR/KWh)	IRR (%)	Effective Period (Years)	Annual Degression Rate (%)	Reference
1	Quetta, Pakistan	50,000	6.0	26	20	7	Current Study
2	Perlis, Northern Malaysia	5	32.1	17	21	8	[20]
3	Kashmar, Iran	120	7.28	32.86	23	7.12	[21]
4	Jamshoro, Pakistan	25	19.84	24.47	25	-	[22]
5	Lefke, Northern Cyprus	1000	24.66	12.9	25	15	[23]
6	Eastern Indonesia	500	17.7	15.6	25	15.6	[24]
7	Port Elisabeth, South Africa	10	14.53	13.56	25	10	[25]
8	Aboisso, Cote d'Ivoire	10	13.62	13.71	25	9.4	[25]
9	Er Rachidia, Morocco	10	11.35	21.70	25	-	[25]
15	Boston, USA	100	16.44	20	30	15	[26]

4.4.2 Comparison of present Study Levelized Cost of Energy (LCOE) with national and international renewable and sustainable energy studies

Table 4.8 depicts the present study comparison of Levelized Cost of Energy (LCOE) with national and international renewable and sustainable energy studies. Comparison results shows that except two studies LCOE of 50 MW power plant in Quetta are cheaper than the different form of renewable and sustainable energies (i.e. wind, offshore, Onshore, Geothermal, Tidal, Hydro, Biomass and Hybrid Energy etc.) in Pakistan and other international countries. Two studies which are cheaper than the present studies are Hybrid renewable energy and Hybrid thermal energy. Hybrid renewable energy are cheaper because it is decentralized and does not needs gird installation cost that's why it's LOCE is low. Cost of Hybrid thermal energy is low because cost of fuel use in plant (such as natural gas, biogas and geothermal energy etc.) are cheaper than any other source. Although cost of hybrid thermal energy is cheaper, but it is expensive in terms of environment as it emits different types of gases (i.e. SOx, NOx, CO, CO_2 and PM etc.) which are causing the global warming, and acid rain etc.

Table 4.9 Comparison of Levelized Cost of Energy (LCOE) with national and International Studies of renewable and sustainable energy sources

Sr.#	Type of Energy	Title	LCOE (PKR/KWH)	Country	Reference
1.	Solar P.V Energy	"Technical and Economic Evaluation of 50MW Solar Power Plant in Quetta"	6	Pakistan	Current Study
2.	Hybrid Energy	"Optimization of Hybrid Renewable Energy Systems (HRES) Using PSO for Cost Reduction"	2	General	[27]
3.	Hybrid Energy	"Levelized Cost of Electricity for Photovoltaic/Biogas	47-60	General	[28]

		Power Plant Hybrid System with Electrical Energy Storage Degradation Costs”			
4.	Hybrid Energy	“2050 LCOE (Levelized Cost of Energy) Projection for a Hybrid PV (Photovoltaic)-CSP (Concentrated Solar Power) Plant in the Atacama Desert, Chile”	25.9-12.95	Chile	[29]
5.	Hybrid Energy	“Feasibility Analysis of a Renewable Hybrid Energy System with Producer Gas Generator Fulfilling Remote Household Electricity Demand in Southern Norway”	67.5-75.5	Norway	[30]
6.	Hybrid Energy	“Levelized Cost of Energy and Cash Flow for a Hybrid Solar-Wind-Diesel Microgrid on Rottnest Island”	34.85	Rottnest Island	[31]

4.5 Rural Electrification

Universal electricity access is possible with the help of rural electrification which is considered to be a fundamental step to fight energy crises. By 2030, it is assumed that every individual will be able to get electricity access irrespective of their area i.e. city or remote area. Off-grid renewable energy is considered to be a solution for this problem because on-grid rural electrification will be costly. As it is discussed in the previous chapter that Baluchistan is the largest province of Pakistan but people there live in tribes and each tribe contains 14 to 20 families. So, it is very difficult to provide on-grid electricity because the tribal areas are far from cities. Rural electrification is the only possible solution for these people to get facilitated by electricity.

During the feasibility of this proposed study it is estimated that the average life of a solar power plant is 25 years but considering the rural electrification it is proposed that the life span of power plant must be reduced to 5 years i.e. only 20 years, power plant should work. After 20 years the rural electrification will be carried out and the solar panels will be installed in the tribal areas in order to provide electricity to under privileged people of the country.

Summary

According to the results our proposed plant will give us a maximum power of 47 MW in summer months While in winter months it will gives us minimum power of 24 MW. You can see in the below table that shows power output in their respective months according to the solar radiation data.

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CHAPTER 5

Recommendation & Conclusion

5.1 Conclusion

The solar radiation data of electricity was used for the techno-economic feasibility of 50MW solar farm. The data was collected from solar radiation devices that have been installed in the Balochistan University of Information Technology Engineering and Management Sciences Quetta (BUITEMS Quetta) by the World Bank and the USAID. By using equation given in literature photovoltaic power was obtained. The LCOE (levelized Cost of Electricity) was used for economic feasibility evaluation of the proposed plant. Technical evaluation of the power plant shows that 91.980 GWh of electricity can be produced per year. The economical evaluation of proposed PV plant shows that it produces electricity at a rate of 0.0385 USD/kWh or 6.09 PKR/kWh for 25-years. The results of this study show that 50MW PV plant will be feasible for Quetta city. As the levelized cost of electricity for this evaluation was three rupees less than minimum quotation of Quetta Electric Supply Company (QESCO).

5.2 Recommendations

- This study recommends that the PV solar plant should be installed at different locations of Quetta city and its nearby areas : Khuchlak , Mustung , and Muslim Bagh
- Due to high solar radiations intensity 50 MW PV Plant Will be most effective rather than in other cities or provinces. Hence, the federal and provincial government should formulate green energy policies to promote renewable energy sources and mitigate the worst electricity crisis in the province (Balochistan).
- This study also promotes the installation of home-based PV panel to counter the electricity shortfall.

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