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Rooftop PV Systems Development in Khyber Pakhtunkhwa: Barriers and Smart Policy Recommendations

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***Abstract*—** The world is faced with the global challenge of climate change and there are two approaches to mitigate the conditions. Decrease the usage of fossil-fuels and increase the contribution of renewable sources to the energy mix, to decrease the Green House Gases (GHG) and carbon footprints. Large solar PV system utilizes a lot of ground space and it poses a challenge to the congested urban centers. This study offers a solution by optimizing the rooftop space for solar PV system through geo-spatial analysis by using multiple modelling approaches satellite image digitization and Arc-GIS. Khyber Pakhtunkhwa is the target of study, where the energy demand-supply comparison and socio-economic analysis have been observed to find the technical barriers and policy barries in the light of existant renewable energy policy with recommendations for future planning.

***Keywords*—** Solar Energy, Photovoltaic Powe System, Renewable Energy Technology, Geo-Spatial Analysis and Energy Management.

I. Introduction

The energy situations of Pakistan have seen the worst dip in the previous decade where the electricity had been not available to the domestic users for more than 12 hours. The statistics show that Pakistan had a total power generation capacity of 15kMW in the year 2010, whereas the requirement was more than 20kMW. For the time being, Government of Pakistan added many non-renewable energy sources that were dependent on fossil fuels and had an uncertain future of sustainability. Resultantly energy prices went up and it pushed Pakistan into the trap of circular debt in energy sector. Poor planning and no consideration for environment and sustainable approaches led to the catastrophe of worst smog condition. Poor policyshift and technical barriers have been the offshoot of an incosistenct energy market.

In all of the renewable energy sources, solar-PV is more suitable for the conditions of Pakistan. Geographically, Pakistan is located on the equator line with a daily average of 4.5kW/m² [1]. According to the Alternate Energy Development Board (AEDB), the total contribution of solar PV into the energy mix of Pakistan is less than 3% [2]. It is far lesser than other developing countries. Primary reason for this low usage is poor quality of solar PV systems and no data for optimization, modelling to derive a suitable policy for renewable energy. The modelling approaches used in this research are novel and proves to be a corner stone for larger optimization of solar PV system in Khyber Pakhtunkhwa. A satellite survey has been conducted using Google Earth Pro, the selected sites high resolution images were digitized using ArcGIS for rooftop space availability. A novel approach of using hill-shade analysis is used in combination with the the available rooftop space for solar PV after digitization. A total rooftop space model has been developed that is further utilized for economic analysis and a comparative policy recommendations.

A. Solar Irradiance

Solar Irradiance is the unit for calculating the power per square meter (W/m²) coming down as electromagnetic radiation to earth from the sun [3]. Irradiance is measured in space or may be at earth surface after absorption in atmosphere and scattering. Irradiance is a function of distance in space from the sun, known as the solar cycle. Irradiance depends on the tilt of the measuring tool on the earth's surface, the sun height above the horizon and the atmospheric conditions.

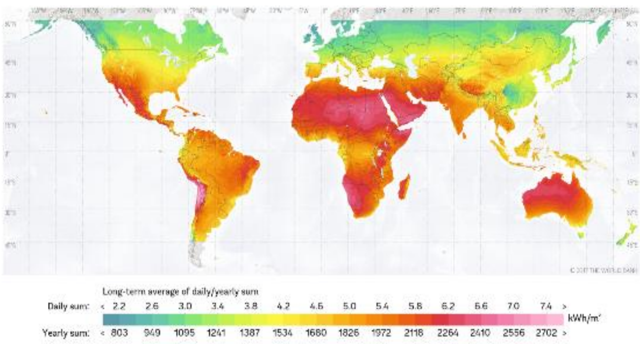

Figure 1. Global Horizontal Irradiance

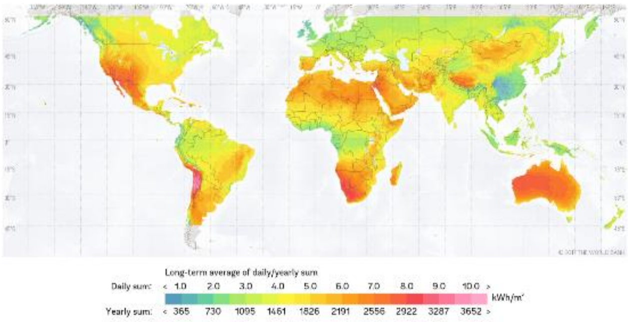

Figure 2. Global Direct Irradiance

Total Solar Irradiance is the sum of solar power at all wavelengths on the upper atmosphere of earth and is perpendicular to the sunlight. One Astronomical Unit (AU) is measure of solar constant.

B. Solar PV System

A Photovoltaic System is a combination of solar panels, in small and large scales, with inverters and other electrical and mechanical hardware, using solar energy to produce power. Solar PV System can be as small as a few panels array on a house rooftop and as large as giant power plants like Solar Parks i-e Quaid e Azam Solar Park in Bahawalpur, Pakistan [4], [5]. PV systems can operate as standalone systems in off grid locations or remote regions and also as grid-tied systems.

Solar energy is a kind of energy that is radiated in the sun light. It gets changed into electrical energy from light energy using the semiconductors, known as energy converters [6]. The converter in general terminology is called a solar cell. The solar photovoltaic are basically two types, light-heat generation and direct light generation.

Solar PV system use the solar cell module to generate electrical energy from solar irradiance. The solar module with the help of a power controller transfer the DC current to the inverter system, the inverter system converts the Direct Current (DC) to an Alternative Current (AC) which is then transmitted for the purpose required [7].

C. Solar Cell

These days there are different types of solar cells. There are different generation solar cells with variation in their structure, shape, durability and efficiency. Silicon based solar cells are widely used in solar modules because of their durability and comparatively mediocre efficiency [8]. The third-generation solar cells have higher efficiency but their durability is questionable. The principle of solar cell is, since it is a composition of semiconductor, the electron-hole nexus forms the potential difference in charge which allows the current to pass through, the current is collected and passed to the controller. The solar module is composed of many solar cells, in series and parallel combination which makes it stronger and effective [9].

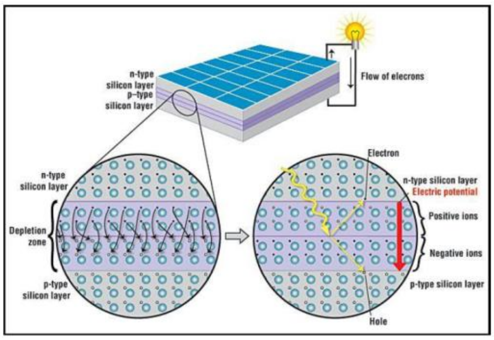

Figure 3. Solar PV Cell

These are various types of solar cells:

- Amorphous Silicon solar cell (a-Si)
- Biohybrid solar cell.
- Cadmium telluride solar cell (CdTe)
- Concentrated PV cell (CVP and HCVP)
- Copper indium gallium selenide solar cells (CI(G)S)
- Crystalline silicon solar cell (c-Si)
- Float-zone silicon.
- Dye-sensitized solar cell (DSSC)

Crystalline Silicon Solar Cell has dominated the world market share of solar cells. C-Si are the most used in commercially available solar panels, having about 85% of the market share with efficiency conversion of about 20% for polycrystalline cells [10]. There are mono-crystalline and poly-crystalline silicon solar cell. Solar Cells made of crystalline silicon are also called traditional, conventional or first-generation solar cells. The crystalline silicon (c-Si) solar cells are single junction cells and more efficient than their rivals second generation thin-film solar cells.

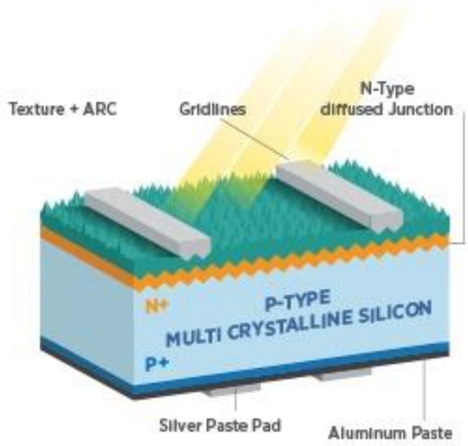

Figure 4. P-Type Crystalline Silicon

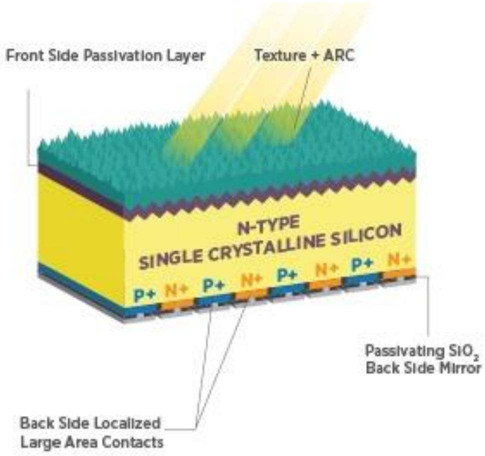

Figure 5. N Type Single Crystalline Silicon

D. *Types of Solar PV Systems*

a. On-Grid Solar PV System

Over the times, advancements have been in solar energy technology, that its use has become inevitable. One of the major and widely chosen type of solar system is the on-grid solar system. The on-grid solar power system is a generation plant which is connected to the main grid. The power generated from the system is directly transferred to the grid which is then used by the consumers at distribution end. At any time, the power that is exceeding the requirement is transferred back to the grid. Usually the on-grid solar system is preferred more than off-grid due to the grid connection and easy operation.

The on-grid solar system works in two directions, the power generated by the plant is transmitted to the consumer's home through the grid, and also in back direction from the consumer's solar system to the grid. It makes the on-grid solar system highly useful with the net-metering to measure the net-cost of the electricity. The operation at the consumer end is the same as that of a solar power plant, the solar panels transfers DC power to the inverter which is then feed to the grid in AC power.

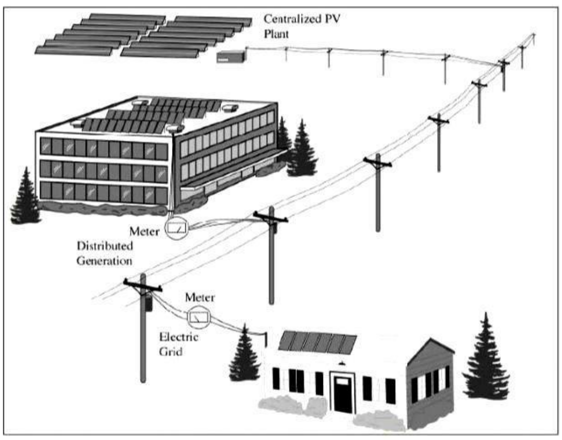

Figure 6. On-Grid Solar PV System

b. Off-Grid Solar PV System

Off-Grid solar system is another type of the solar power systems, it is also called stand-alone power system (SAPS) due to its independent operation. The off-grid solar system generates power from solar panels, and charge the batteries through controller. Inverter system is used for converting the Direct Current (DC) to Alternating Current (AC) for the usage purpose at home. Batteries are used so that there is non stop power supply even at night time, when the solar panels stop working or at times where the solar irradiance is less.

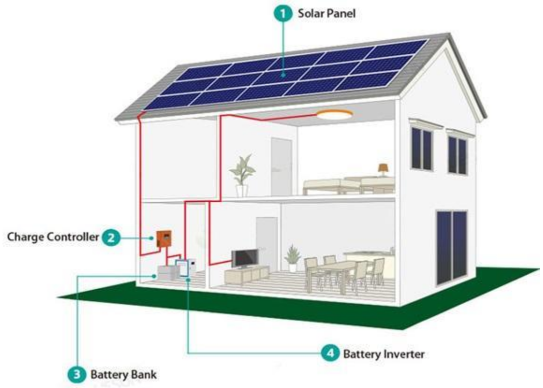

Figure 7. Off-Grid Solar PV System

c. Hybrid Solar Power System

As the name suggests, hybrid solar power system is a combination of different generation sources and produce power in same fashion as that of an on-grid solar system but the difference is mainly in inverters, instead of the normal inverters, hybrid inverters are used and the battery bank store energy for later use, also operate as the backup supply in case of blackout, similar to the uninterrupted power supply system (UPS).

Conventionally, the hybrid refers to two generation sources like solar or wind, however it is observed that in the solar world, the hybrid refers to a combination of solar and many other energy sources, that are also connected to the grid.

Figure 8. Hybrid Solar PV System

E. *Energy Policy*

The energy policy of Pakistan is planned and formulated by the federal, provincial, and local institutional elements in Pakistan, which address the issues of energy production, distribution, and utilization of energy, for example, gas mileage and oil guidelines. Energy policy requires the best possible enactment, universal bargains, appropriations and motivators to venture, rules for energy conservation, tax collection and other open policy procedures.

II. METHODOLOGY

The trickiest part of the research was the assessment of locations to be picked for detail solar irradiance estimation. Khyber Pakhtunkhwa's energy demands and relationship of Socio-Economic structure and the cost of energy. Since Khyber Pakhtunkhwa lies in the North West of Pakistan, and is a longitudinal province with variance in elevation and solar irradiance, it was deemed feasible to pick multiple locations for detailed analysis. Ideally the entire province estimation is possible but not practically due to lack of resources and accessibility.

A. Peshawar

Peshawar is the capital city of Pakhtunkhwa; it is very large and getting a high-resolution satellite image of the entire city for digitization is nearly impossible, therefore, Hayatabad was selected for a detailed and specific location.

B. Mardan

Mardan is one of the major cities of the province and contributes about second largest share to the revenue of the province, it is ideal for being a home to second biggest division in the Peshawar Valley, having a diverse population and a symmetrical housing society.

After selection of these locations, a geographic survey was conducted on Google Earth Pro software, to target the particular location, that has all the specifications required for this study. After a detailed survey of the geographic high resolution and update maps of these locations, a target location was selected in all regions.

The target location had the following specifications:

- Symmetrical buildings, having similar image patterns and shapes of the rooftops.
- Close knitted houses, for an accurate measurement and estimation.
- Widely known housing societies or townships, being home to a mixture of socio-economic classes.
- Standardized buildings and proper gaps for less shadow effect.
- Areas connected to National Grid for Net Metering.
- Off Grid for Remote Areas as an alternative solution.

C. Solar Irradiance

After extracting the total rooftop area of the targeted regions, it was deemed fit to further estimate for the available solar irradiance in these regions. For this purpose, SolarGIS was used to extract data of these regions, the data included the following main specifications.

- Avg PVout with Annual Irradiance details
- Temperature Charts
- Population Density
- Elevation

The SolarGIS maps intercorporate into the already available ArcGIS data for a detailed analysis of the region, in the light of solar PV-out estimation, in kW per day. Now after extracting the rooftop solar PV out data of the targeted locations, the software PVsyst was used for proposing a solar PV system that suits the conditions of the location. For this purpose, the coordinates of these locations were used as target locations and the software analyzed an ideal 2kW system for all the rooftops, given the average area available.

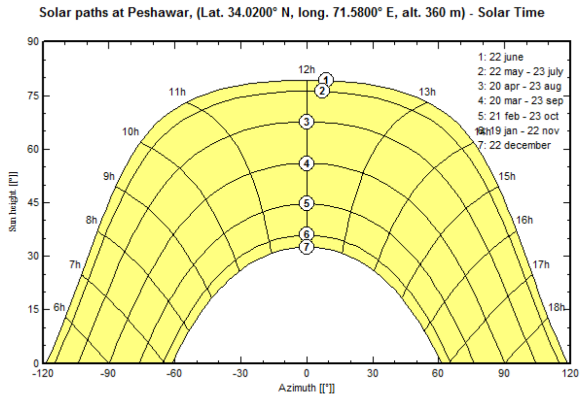

Figure 9. Solar Path in Peshawar using PVSyst

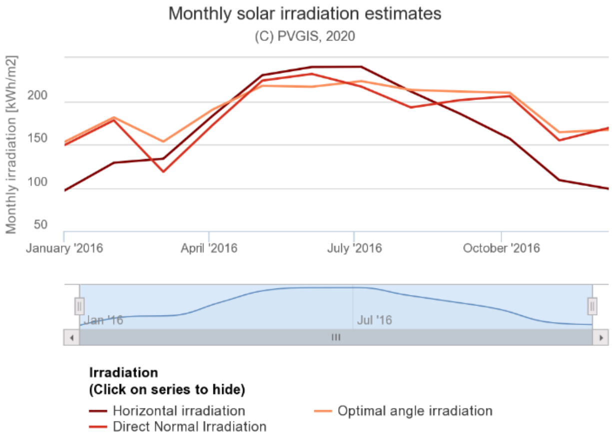

Figure 10. Monthly solar Irradiance estimation

III. RESULTS

The simulation results show the irradiance in the targeted locations with technical specifications that there is a profound rooftop solar PV potential available in Khyber Pakhtunkhwa, as shown in the results of figures and estimates. The government of Khyber Pakhtunkhwa should show serious attitude in the drafting of a smart policy in the light of given technical specifications and empirical approach to meet the energy market.

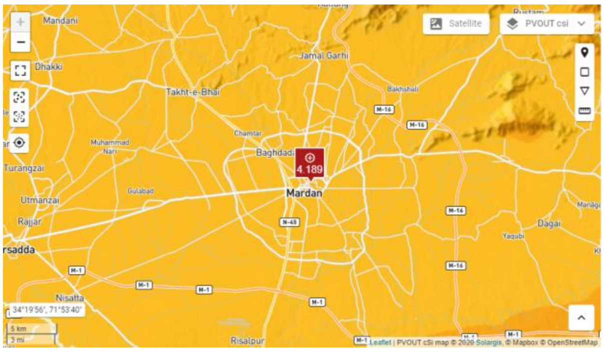

Figure 11. Solar Irradiance Map of Mardan

The above figure is an image of Solar GIS projecting the PV potential of the District Mardan and the surrounding regions, that is about the same 4.1 kWh per day. The city of Mardan lies on the bank of a river named Kalpani, however there is less to none hydroelectric infrastructure. Mardan has developed a lot in the recent past and it contributes the second highest revenue to the provincial exchequer, but still the average family income is pretty low, out of many factors, expensive energy is one. If the cost of energy is decreased by any mean, Mardan has the potential of rising the socio-economic graphs. To project these, a sample location of Sheikh Maltoon Town is selected for digitization.

TABLE 1. SPECIFICATION OF TARGETED LOCATION IN MARDAN

Area	Size (m^2)
1 Kanal	504
10 Marla	252
7 Marla	180
5 Marla	126

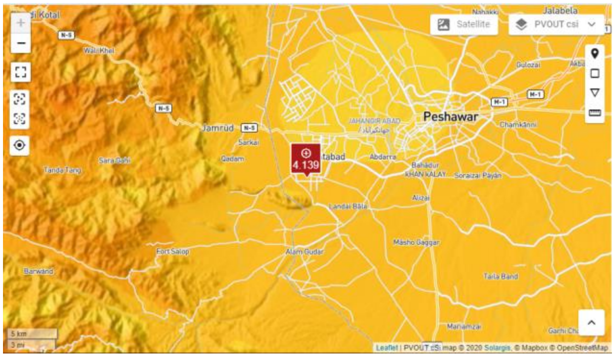

Figure 12. Solar Irradiance Map of Peshawar

The above fig. 12 is a SolarGIS image of Peshawar and the surrounding region, showing solar PV-out potential per sq-meter area, that is about 4.139 kWh/m². This location is further simulated for digitization of available rooftop PV potential.

It is the only sector in the entire Hayatabad city that is vastly populated and has fewer empty plots. Empty plots in our case is a waste of area because they are not feasible for installation of a PV system due to shadow effect from the side buildings. A survey visit was conducted to the selected location, the physical investigations found that most of the homes built in this location are fully covered, that indicates that the area of rooftops are mostly equivalent to that of the entire plot but still delicate estimations are made in this study to further increase the accuracy of the study.

Figure 13. Sample digitized rooftop space in Peshawar

The yellow line in Fig. 13 indicates the total area of single roof while the red line indicates the area required for PV system. I have digitized few roofs as sample to be applied over the entire sector. ARC-GIS software is used to digitize the rooftops to figure out the topography of the area.

TABLE 2. SPECIFICATION OF TARGETED LOCATION IN PESHAWAR

Features	Scale
No of Plots (5 Marla)	880
No of Rooftops	748
Avg Rooftop Area (m^2)	74
Total Rooftop Area (m^2)	55,352

In the above given tab. 1 and tab. 2 the specification of targeted locations in terms of rooftop places available has been specified. It shows that both the major urban centers of Khyber Pakhtunkhwa have good enough potential available. Only the targeted urban centers have shown a great solar PV potential available with the technical features and feasibility.

The tab. 3 suggests the technical specification of the targeted location in terms of the slope angle for titlted PV array and the azimuth and angle for maximum efficiency. The yearly PV average has also been indicated.

TABLE 3. TECHNICAL SPECIFICATION OF LOCATION

Features	Scale
Slope Angle	34 (opt)
Azimuth Angle	-7 (opt)
Yearly PV Energy	1490 kWh
Yearly In-plane irradiation	2110 kWh/m²

In the tab. 4 the cost of a solar PV system with current marker prices have been indicated for the full scale optimization, and the payback periof of upto 5 years have been calculated with the current price of electricity ratio to the cost of solar PV system.

TABLE 4. COST OF SOLAR PV SYSTEM

Sr. No	Component	Cost ($) / watt
1	Solar PV Module	0.5
2	Inverter	0.25
3	Installation Cost	0.3

CONFLICT OF INTEREST

The authors have claimed no conflict of interest in this research article by the authors.

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Afraz Ahmad and Owais Ahmad dedicate this research study to the great Mardan Association, that has been part of all the hurdles we faced while going through this novel and enlightened journey of research. We specifically appreciate the role of Engr. Sheraz Khan, Engr. Kamran Khan and Engr. Rashid Mahmood and the prestigious institution of Center for Advance Studies in Energy (CAS-E), UET Peshawar.

CONCLUSION

After simulation and estimation, it has been concluded that a small part of the rooftop is selected, and a great amount of energy can be produced through these small portions. Each rooftop average area is 75 sq. meter and a system of 2kW covers up to 30 sq. meter area, producing on average 8.8 kilo watt-hour energy daily for the proposed system.PV potential from Hayatabad Phase-6 F-6 sector house's rooftops is sought out in this study. Also, it provides a detailed insight of PV energy potential. The main outputs from this study, estimation of solar irradiance through simulation in study area, and the total energy potential available on the rooftops of the study area. In this study, we found that there is a great amount of photovoltaic potential available for electricity production on the rooftops of Hayatabad F-6 sector, that is 2,453,450 kWh annually. In comparison to the energy consumption of this sector, it is approximately 60% of total energy consumption of this sector. And there is still good enough space for further upgradation of system on the rooftop.

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