

Solar Energy Technical Potentials Analysis of Khyber Pakhtunkhwa based on GIS and Multi-Criteria Method

Asif Zarin

Department of Electrical Engineering University of Engineering and Technology Peshawar, Pakistan
Asifzarin99@gmail.com

Received: 09 January, Revised: 21 January, Accepted: 22 January

Abstract— Pakistan is located just above the tropic of Cancer; this offers most optimal locations on the globe for Photovoltaic power generation. Khyber Pakhtunkhwa has an average solar insolation value more than 5.0KWh/m²/day, which is very appropriate for Photovoltaic deployment. But Photovoltaic power generation trend shows considerably less progress in this region. The aim of this research is to assess the solar potential for photovoltaic power generation in Khyber Pakhtunkhwa province by identifying feasible sites both technically and economically for a utility-scale solar power park installation. The feasible sites were identified using Geographic Information Systems (GIS) software. This process uses Multi-Criteria Analysis method to meet different criteria such as solar irradiation, slope and aspect combined with proximity to transmission lines and roads plus a number of limiting factors. The final results showed that 8% (8,000 km²) of the research area is highly suitable for installing utility-scale photovoltaic parks. A total of 18 sites with suitability value of 9 and area greater than 6 km² have been identified in South and South western part of Khyber Pakhtunkhwa. In addition, 70 areas of suitability value between 7 and 8 having areas 2-4 km² have been identified. Calculations were carried out to find the technical potential for power generation. The results showed that appropriate amount of feasible areas are available for large scale PV installations, with adequate power generation potential.

Keywords—: Energy, Irradiation, Renewable, Suitability, Technical.

I. INTRODUCTION

Renewable energies are the fastest growing source of energy and considered to be the solution for achieving power system sustainability. According to International energy agency renewables will provide 30% of the total power demand in 2023, as it was 24% in 2017. It is forecasted that during the period from 2018 to 2023, 70% of the world power generation growth will be provided by renewables [1]. For solar plant, large area is required which causes adverse influence on biodiversity, land use, and land cover. Ideally, solar installations should be situated on vacant, low productivity agricultural land or on barren land and lands covered by bushes to minimize such impact. Non-

ideal sites are extreme far off location, insecurity and high degree of development and covered by forest [2]. The distance of solar park from urban population is also very important. The Solar plant installed near load centers will have to cover a smaller distance and the transmission lines required to transfer the energy produced will much less, thus reducing energy loss and cost of the energy supplied to consumers [3, 4]. However, choosing suitable sites for harvesting solar energy is not a straight forward task. It is based on multiple sets of physical, environmental and socio-economic criteria in order to decide optimum geographic locations. Hassan et al. [5] used GIS-AHP method for site selection for solar power park in Saudi Arabia. Two type of criterion were considered i.e. technical and economical. Technical criteria involve are solar irradiation and the air temperature. Economic criteria involve slope, aspect, Vicinity to power lines, vicinity to cities and vicinity to highways. The constraints considered were high slope, land use and protected areas comprising of industrial cities, agricultural land, national parks, holy places and wildlife sanctuaries. The study was divided into four steps. First step was ruling out unsuitable sites. In second step an Analytical hierarchy process method was used to find out the priority weight and relative importance of all criterions. The next step involved overlaying different criteria maps as an input criteria according to their relative weights obtained in step 2 (AHP) to create an integrated analysis. The weighted sum overlay accepts the scaled inputs, and adds them together. In final stage a land suitability index was developed to show the potential sites suitability distribution for solar PV installation.

Carolina et.al [2] applied Geographical Information System (GIS) and multi criteria method to assess the solar energy potential for electricity generation in Europe. Factors determining the overall suitability (proximity to Electrical grid and transportation network, slope, aspect, solar irradiation and Population) and different Constrains were identified. Unsuitable area identified were forest, wetlands, water bodies, and land use whereas undeveloped and short vegetation areas were considered as the suitable location. Slope was identified as the main suitability factors for land suitability criteria. (Slope between 16 and 30 was considered poor while above 30 were restricted), solar irradiation (below 900kWh/m² fall in Poorest regions), Proximity to Road network (5000 m cut-off value), the

distance to the existing electrical network (grids) and population considered as small as possible. All the individual criterion factors maps integrated in single layer using weighted linear addition technique in GIS to evaluate the total suitability. As a validation exercise comparison between existing solar powers parks and suitable sites was carried out. The comparison indicates that existing solar power parks matched European suitability model overlaid in the study.

II. METHODOLOGY

Khyber Pakhtunkhwa, Pakistan is selected as study area on the bases of its ideal conditions for solar installation and large area. The total area of the Province is 101,741 square km of mix terrain, and has annual average irradiance values greater than 1760KWh/m² according to the National Renewable energy laboratory (NREL) solar database. Steps involve are:

Calculate the total suitable area;

- Find out how much renewable energy resource is present within the calculated areas;
- Finally calculate the amount of electrical energy that could possibly be generated from that available area, based on currently available PV technology [6].

A. Land suitability criteria:

Land suitability is based on the following six criteria and number of limiting factors.

i. Solar Irradiation (kWh/m²)

The NREL is a leading industry for renewable energies projects development and installation. The data provided by NREL is most credible and is being referenced in literature of a lot of scholars. NREL is US based organization that provides free data, and have compiled a number of useful datasets for

utility-scale or large distributed renewable energy development. The Solar data used in this study was acquired from the National energy laboratory. When assessing potential sites for PV projects, the most important parameter to consider is solar radiation levels [6 - 8]. The solar analyst tool in the ArcGIS software was used for solar irradiance analysis and mapping [9]. The solar irradiation (GHI) for Khyber Pakhtunkhwa is divided in 5 classes. Solar irradiation for the study area is illustrated in Figure 1.

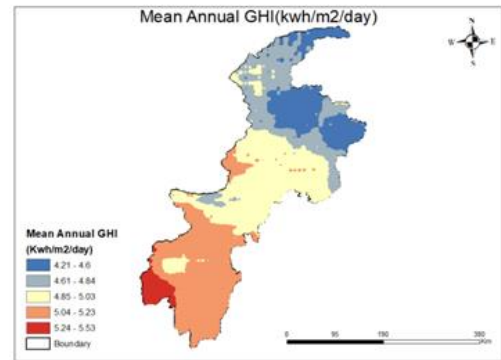


Figure 1. Mean Annual GHI

Electricity generation from solar energy could be the most appropriate source of energy to cope with the rising electricity demand because the pattern of global solar irradiation exactly follows that of electricity demand. It varies accordingly with seasonal variation [4]. Figure 2 shows Seasonal Variation of Solar Irradiation.

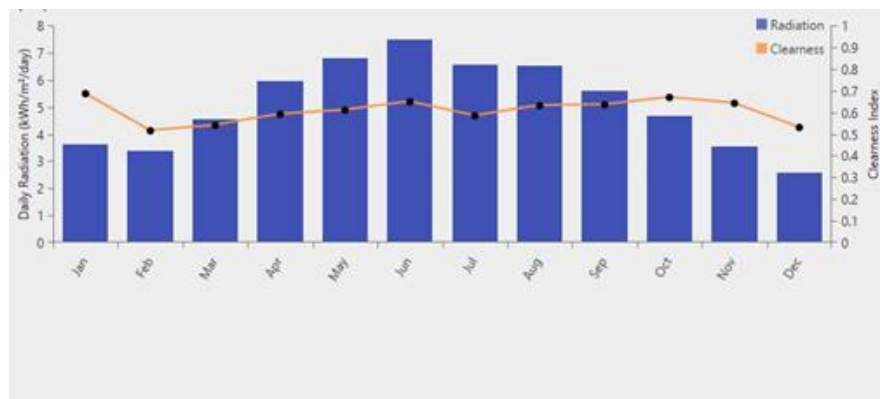


Figure 2. Seasonal Variation of Solar Irradiation

ii. Slope

Level plains or minor steep slopes require less construction cost as compared to high slopes areas. So, for economic feasibility flat terrains are vital for utility-scale PV parks [10]. For slope calculation Spatial Analyst toolbar (slope tool) in ArcGIS used. For an entire area a slope raster is created. This

slope raster enables to get an impression of the steepness of the terrain, that can be used the output for further analysis. Results for slope are illustrated in Figure 3.

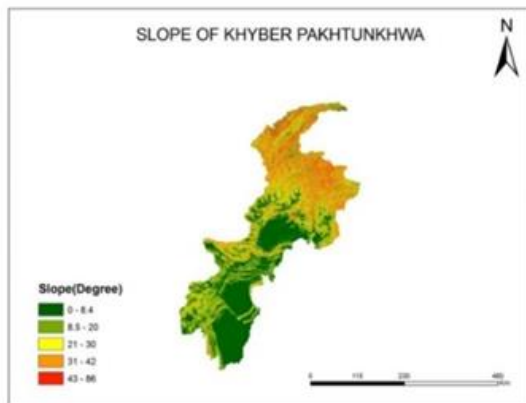


Figure 3. Slope of study Area

Lands having Slope value less than 5° are highly suitable for PV installation whereas $5-10^\circ$ considered as moderately suitable [11]. Figure 3 shows the slope of study area.

iii. Aspect

Spatial Analyst toolbar in ArcGIS calculates the maximum rate of change in value between two neighboring cell. Aspect has a direct influence on solar radiation. In northern hemisphere, the slopes facing north are mostly shaded, whereas slopes facing south receive more solar radiation because these are tilted towards the sun and the earth do not directly shade these areas. Figure 4 shows result for aspect.

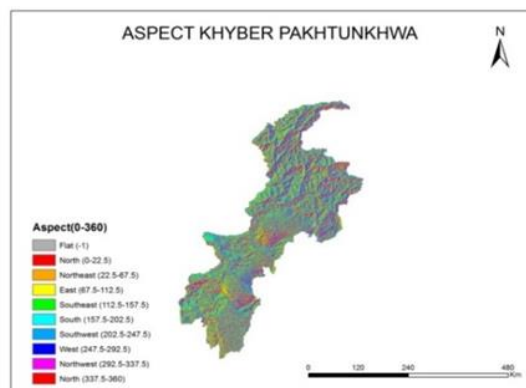


Figure 4. Aspect of study Area

iv. Elevation

ASTER DEM (30m) has been use for calculating the aspects values. Figure 5 shows Elevation of Khyber Pakhtunkhwa.

v. Distance to Transmission line and Road Network

Distance of a PV park from transmission lines is important because of two main reasons; resistance of conductor is directly proportional to length of the conductor so electrical losses in transmission lines increase with the increase in length. Secondly constructing new power lines can raise the overall cost of the project [12]. The distance between the source and transmission line was considered as one key factor [6-8,13,14,15]. The distance functions in Spatial Analyst tool was used to find

proximity to electrical network. Figure 6, displays the distances from transmission line.

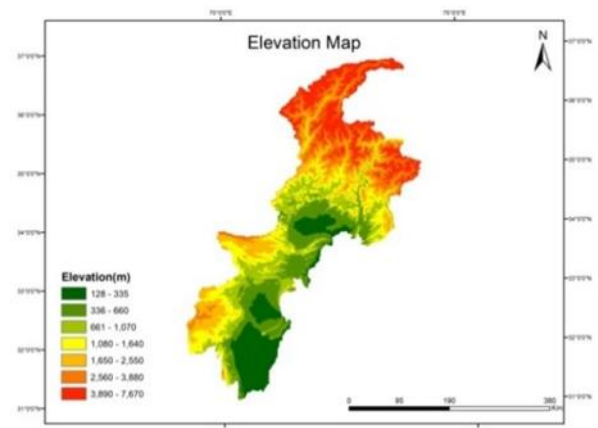


Figure 5. Elevation of KPK

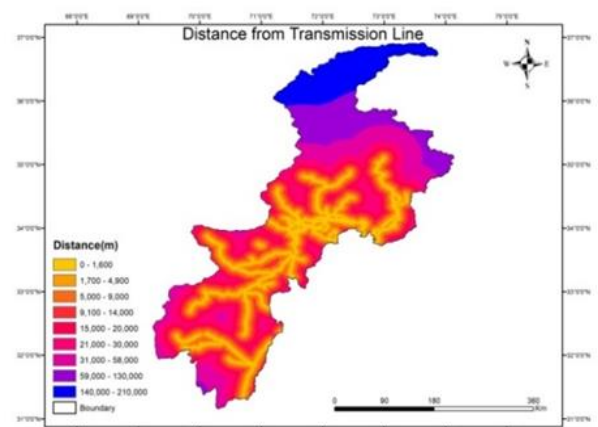


Figure 6. Proximity to transmission line

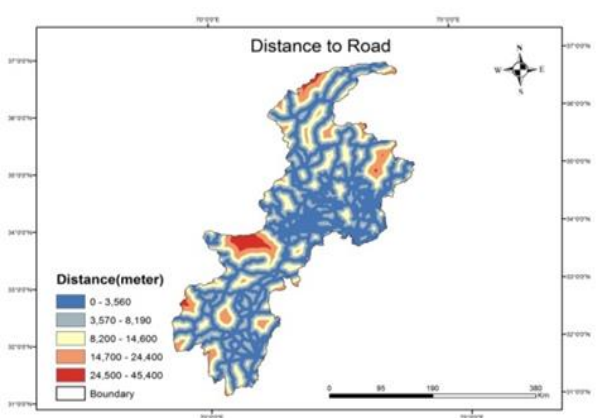


Figure 7: Proximity to Roads

Areas < 250 meter are excluded from the study, to counter the decrease in module efficiency and damage caused by social activities, such as dust due to traffic or any other reason and construction activity [16]. Accessibility to potential sites proves

to be an important factor. Road accessibility is necessary for construction, installation and maintenance throughout the life of solar park. Solar power park proximity to a main road considered an economic factor [7, 8,12, 14, 15]. Figure 7, shows Proximity to Roads.

vi. Land use and Land cover

Land cover and land use were considered as constraints in this study. Most common restrictions and Constraints applied for Utility-Scale solar site are Parks, Water, Wetlands, Forests, Wildlife Areas, Urban lands, cultivated and protected land [7-11, 14-16]. These constraints are excluded from the suitability model. Gaussian Maximum Likelihood algorithm of supervised classification was used to extract different features. The result is shown in figure 8.

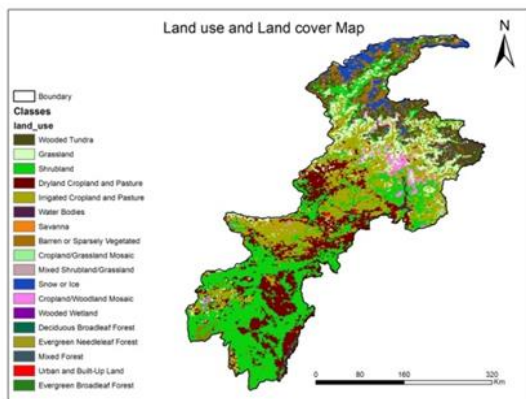


Figure 8: Land use and Land Cover

B. Analytical hierarchy process

Analytical hierarchy process (AHP) offers the perfect compromise solution for contradictory objectives [17]. AHP method has been employed to calculate weight for different parameters which give importance of a parameter for decision making. Table I shows Pair wise comparison matrix.

TABLE I. PAIR WISE COMPARISON MATRIX

Elevation	Road	T/L	Slope	Aspect	DNI	Pair wise compression matrix
7	5	5	3	2	1	DNI
6	3	3	2	1	0.25	Aspect
5.00	3	3.00	1	0.33	0.2	slope

TABLE III. TOPOGRAPHIC AND METROLOGICAL FACTOR RATING

GHI	Rating (GHI)	Aspect	Rating (Aspect)	Slope	Rating (slope)
<4	Restricted	Flat(-1)	9	0-5	9
4.2-4.6	5	North (0-22.5)	1	5-10	8
4.61-4.84	6	NE (22.5-67.5)	2	11-30	Restricted
4.85-5.03	8	E(67.5-112.5)	3	31-42	Restricted

2.00	1.00	1.00	0.30	0.25	0.16	T/L
2.00	1	1.00	0.33	0.25	0.16	Road
1	0.5	0.5	0.20	0.16	0.11	Elevation

On applying AHP method [17], weight of each criterion is obtained and is shown in Table II.

TABLE II. PERCENTAGE WEIGHT OF EACH FACTOR

Category	Priority	Rank
1	DNI	0.4
2	Aspect	0.24
3	Elevation	0.04
4	T/L Network	0.075
5	Road	0.075

Before overlay each criteria layer is reclassified using reclassify tool into classes. When we reclassify a raster, a new raster is created with the reclassified values. The new value is based on a ranking scheme usually 1 to 9. In the third stage, final result has been modelled by applying weighted sum overlay method using the ArcGIS software. Weighted sum overlay technique involves overlaying various factors maps (irradiation, slope, distances to road and electrical network) according to their relative weights obtained from AHP. A suitability index has been prepared to categorize the province on the basis of potential solar harvesting site based on the weight of contributing factors. Restriction factor like "GHI" less than 4 KWh/m²/day and lands having slope higher greater than 10° were excluded. Slope less than 5° are most suitable [7, 13]. The suitability index map ranging from 1-9 has been generated. The suitability model is based on six model criteria and restriction factors. Table III shows topographic and metrological factor rating and Table IV economic factors rating. A priority values ranging from 1-9 has been assign to each factors and the corresponding values by considering various economic, environmental as well as technical aspects. Sites considered extremely suitable were assigned a rating of 9, whereas sites with the least suitability were set a rating of 1 or restricted.

5.04-5.23	9	SE(112.5-157)	8		
5.24-5.53	9	S(157.5-202.5)	9		
		W(247.5-292.5)	9		
		NW(292.5-337)	4		
		N(337-360)	1		
		SW(202-247)	8		

TABLE IV. ECONOMIC FACTORS RATING

Distance from network	Rating (Distance from network)	Distance to Road	Rating (Distance to Road)	Land cover
0-0.5	Restricted	0-3.5	9	Barren land
0.5-6.5	9	3.5-8.2	8	Other
6.6-18	8	8.3-15	7	
19-30	6	16-24	5	
31-43	3	>25	1	

Applying the above rating, restrictions and Weighted overlay technique. The suitability model is obtained as shown in figure 9.

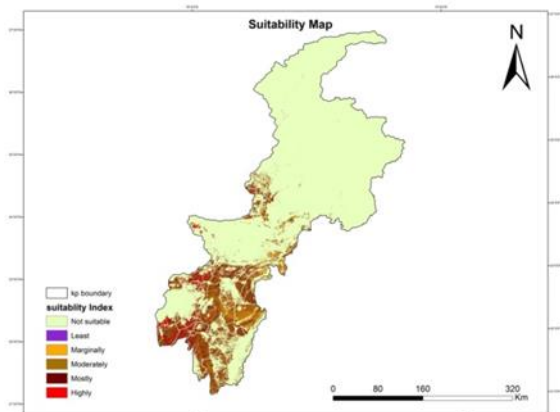


Figure 9: Suitability Map

C. Site selection Results

The Constrains, for instance agricultural land, urban areas, protected areas (National park, holy places etc.) and roads were excluded from the study. The last step in identifying the best suitable sites was to make sure that the potential sites have sufficient area for installing utility scale PV Park. Figure 10 indicates the potential sites for the study area. For utility-scale solar PV power park areas having area greater than 1 km² and suitability index from 8-9 are consider to be that the potential sites [6].

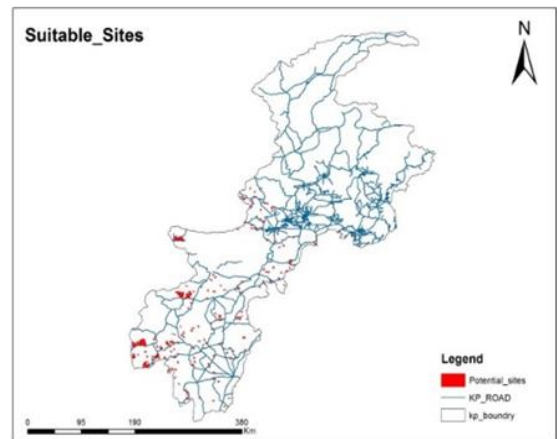


Figure 10: Final suitable sites

TABLE V. SUITABILITY INDEX

Suitability index	Scale
Not Suitable	0-5
Least	5-6
Marginally	6-7
Moderately	7
Highly	8-9

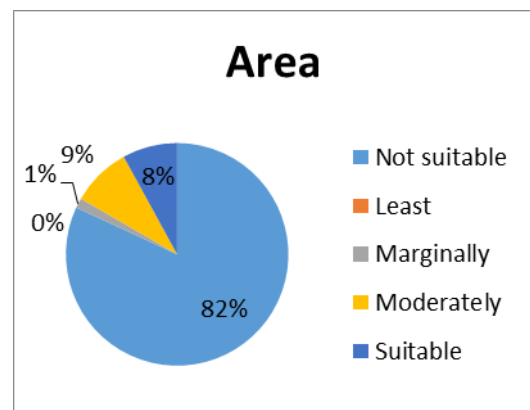


Figure 11: Suitability Index

The result of MCDM-GIS integration showed that 8% (8000 km²) of the concern area is highly feasible for installing solar Photovoltaic power parks as shown in figure 11.

D. Electrical potential Assessment Methodology

Total Solar Insolation in the suitable area [6].

$$I_{\text{Total}}/\text{year} = \text{Area} \times \frac{I_{\text{Avag}}}{\text{m}^2} / \text{day} \times 365 \quad (1)$$

$$I_{\text{Total}}/\text{year} = 8 \times 10^9 \text{m}^2 \times 5 \text{kwh/m}^2 \times 365$$

$$I_{\text{Total}}/\text{year} = 14,600 \times 10^9 \text{ kwh/year}$$

Total electrical energy generation

$$\frac{\text{KWH}}{\text{Year}} = I_{\text{Total}} \times \eta \quad (2)$$

$$\frac{\text{KWH}}{\text{Year}} = 14,600 \times 10^9 \text{ kwh/year} \times 0.15$$

$$\text{Total generation} = 2,190 \times 10^9 \text{ kWh/year}$$

CONCLUSION

The method used in this research work successfully identified feasible sites (areas) for photovoltaic deployment based on different criteria and multiple stages of evaluation. This research work has tried to address the problem in two ways, first presenting the results in cartographic form, which provide a significant amount of information. Secondly through the use of tables and graphs that provides a quantitative view of the results, creating a relation between values and their respective locations in space. The research consists of two main parts, in first step a site suitability analysis was conducted and in second, calculation for technical potential and power generation capacity was carried out. The overlaid results obtained from the analysis showed that 8% area is highly suitable and 10% of the study areas have moderate suitability levels. The total insolation for suitable area is 14,600×10⁹ kwh/year. This insolation can be converted into electrical energy using PV panels having efficiency of 15% with optimum tilt angle. The electrical energy generation after all the necessary calculation equals to be 2,190 ×10⁹ kWh/year. For utility-scale projects areas less than 1km² were excluded from the suitable areas to make sure that total size of the land is large enough to be considered for a project. The results of the research indicated that, substantial amount of suitable sites with adequate power generation potential are available for a utility-scale Photovoltaic installation. So it can be concluded that the study area is very feasible for on grid or off grid system PV deployment. Particularly the area far away from the national grid off grid solar PV can be very good choice.

FUTURE WORK

This research can be extended in future:

- A survey on social and political acceptance will be very supportive.
- Finding out the solar sites and the effect on voltage profile on proximate electrical buses, maximum power injection limits and transmission line losses.

- The proposed methodology is flexible, it can be easily modified and additional physical, environmental and planning economic can be included in it.
- Expand the work to evaluate the economic costs, benefits, risks and hazards associated with developing the selected sites.
- The proposed methodology can also use for other renewable energy system such as biomass, hydropower and geothermal.

REFERENCES

- [1] International Renewable Energy Agency (IRENA) Online available <https://www.irena.org/>
- [2] C. P. Castillo, C. Lavalle, and F.B. Silva, " An assessment of the regional potential for solar power generation in EU-28" Energy Policy 24 October 2015.
- [3] M. Tahri, M. Hakdaoui, M. Maanan "The evaluation of solar farm locations applying Geographic Information System and Multi-Criteria Decision-Making methods: Case study in southern Morocco" Renewable and Sustainable Energy Reviews, vol. Vol.51, , pp.1354-136, November 2015.
- [4] F. Albuyeh and A. Ipakchi, "Grid of the future" IEEE Power & Energy Magazine, vol. 7, no. 2, pp. 52–62, 24 Feb 2009.
- [5] H. Z. Al Garni, and A. Awasthi "Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia," Applied Energy, vol. 206, pp. 1225–1240, 15 Nov 2017.
- [6] A. Lopez, D. Beckley and E. Doris, " Geospatial Analysis of Renewable Energy Technical Potential on Tribal Land" CO: National Renewable Energy Laboratory, February 2013.
- [7] J. R. Janke, "Multicriteria GIS modeling of solar and wind farms in Colorado," Renewable Energy, vol. 35, no. 10, pp. 2228–2234, October. 2010.
- [8] C. H. Antunes, J. M. Sánchez-Lozano, L. C. Dias and M. S. García-Cascales, "GIS based photovoltaic solar farms site selection using ELECTRE-TRI, Evaluating the case for Torre Pacheco, Murcia, Southeast of Spain," Renewable Energy, vol. 66, pp. 478–494, Jun. 2014.
- [9] A.A. Merrouni, A. Mezrhab and A. Mezrhab, "PV sites suitability analysis in the Eastern region of Morocco," Sustainable Energy Technologies and Assessment, vol.18, Dec 2016.
- [10] O. Nait Mensour B.El GhazzaniB. HliimiA.Ihlal "A geographical information system-based multi-criteria method for the evaluation of solar farms locations: A case study in Souss-Massa area, southern Morocco" Energy, Vol. 182, 1 Sept 2019.
- [11] A. Zakaria, M. L. Sabo, M. A. Mohd Radzi, N. Mariun and H. Hizam, "Spatial matching of large-scale grid-connected photovoltaic power generation with utility demand in Peninsular Malaysia," Applied Energy, vol. 191, pp. 663–688, 1 April 2017.
- [12] A. Paduru, D. Hurlbut, D. Corbus, E. Ibanez, P. Schwabe, M. Hand, G. Brinkman, V. Diakov, and M. Milligan, "California-Wyoming Grid Integration Study Phase 1 Economic Analysis California-Wyoming Grid Integration Study Phase 1 — Economic Analysis," 2014.
- [13] E. B. Mondino, R. Chiabrando and E. Fabrizio, "Site Selection of Large Ground Mounted Photovoltaic Plants, A GIS Decision Support System and an Application to Italy," International Journal of Green Energy, vol. 12, no. 5, pp. 515–525, 8 Dec 2014.
- [14] M. Welsch, D. Mentis, O. Broad and H. Ronger "A GIS based approach for Electrification planning, A case study on Nigeria," Energy for Sustainable Development, vol. 29, pp. 142–150, 28 Sept 2015.
- [15] A. Gastli and Y. Charabi, "PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation," Renewable Energy, vol. 36, no. 9, pp. 2554–2561, Sep. 2011.
- [16] A. Miller and B. Lumby, "Utility Scale Solar Power Plants - A Guide for Developers," 2012.

- [17] L. G. Vargas and T. L. Saaty, "Models, Methods, Concepts and apps of the Analytic Hierarchy Process", 2nd Edition. New York: Springer US, 2012."

How to cite this article:

Asif Zarin "Solar Energy Technical Potentials Analysis of Khyber Pakhtunkhwa based on GIS and Multi-Criteria Method", International Journal of Engineering Works, Vol. 8, Issue 01, PP. 47-53, January 2021, <https://doi.org/10.34259/ijew.21.8014753>.

