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Optimal Site Selection for Solar PV Power Plant in an Indian State Using Geographical Information System (GIS)

Ghazanfar Khan[1], Shikha Rathi[1]

[1]Mechanical Engineering Department, BITS-Pilani Hyderabad Campus, India

Abstract: *Efforts to incorporate renewable energy sources have been brought. Due to the challenge of an increasing demand for electricity worldwide, depletion of conventional generation facilities, along with the consequences of greenhouse gas emissions from existing conventional energy sources. One important aspect for achieving such highly ambitious plans is to identify the promising geographical areas. This paper presents a decision and methodology to locate potential sites for large-scale Solar PV (SPV) plants focusing on various factors. Factors have classified as "analysis criteria" and "exclusion criteria". The criteria such as Availability of solar radiation, Availability of vacant land, Distance from highways and existing transmission lines etc. have considered as analysis criteria. Variations of local climate, module soiling, topography of site etc. areexclusion criteria. Indian state Rajasthan has chosen as a case study based on the highest solar radiation available in India. A series of maps have been created by GIS software to illustrate possible locations for large-scale SPV power plant. Resulting locations have been analyzed by exclusion criteria. The area which is situated at 26.92^{0}N, 70.900^{0}E with the maximum summer temperature of 43^{0}C hasbeen chosen as most suitable site for SPV plant in Rajasthan*

1. INTRODUCTION

From the environmental and energy security perspective, it is an established fact that the dependence on conventional energy resources hasto be reduced and renewable energy resources are one of the promising options available to meet this. Of all the several renewable energy resources solar energy is the most promising option because of its inherent advantages. While thermal route of harnessing solar energy for electrical power generation is being used for quite some time, of late, the PV route to harness solar energy for electrical power generation is being promoted in a big way across the world. For instance, in India, (where there are 250 to 300 clear sunny days a year in most parts of the country with an annual global radiation varying from 1600 to 2200 kWh/m^2 [1]) under the highly ambitious program viz. JNSNM, it has been aimed to establish 20000 MW by the end of 2022 year. [2]. One important aspect for achieving such highly ambitious planis to identify the promising geographical areas for establishing such SPV plants since with the existing low conversion efficiencies, installation of solar PV power plant requires enormous amount of investment in terms of land, money and manpower.

In the global context, works reported by Adel Gastli, YassineCharabi [3, 4],Herrera-Seara et al [5],are among the several works that suggested the methodologies to arrive at the optimal sites for different renewable energy power plants. However, works reported by Hossain et al [6] on wind farm potential in India, Mahmmud et al. [7,8]on economic potential of different renewable technologies in Karnataka, SouvikGanguliandJasvir Singh [9] on solar photovoltaic potential and capacity of plant in Patiala, are among the few works reported on various renewable energy technologies in the Indian context.

The Indian state Rajasthan is one of the states where the potential for harnessing solar energy is extremely large. Geographically, Rajasthan is uniquely placed to tap solar radiation with 300 to 330 clear sunny days and average daily solar incidence of 5-7 kWh/m^2/day. The total deserted area in the state is 208110 km^2 and 60% of the land is arid and semi-arid. Large amount of it is contiguous, relatively flat and undeveloped [10].

In Rajasthan the share of thermal energy stood at 68.6% of total installed capacity. The other major source of power is hydro power, which accounts for another 26% of installed capacity. Rajasthan presently has a well-defined Non-Conventional Energy Policy and Wind Policy, renewable sources of energy but it accounts for about 5.4% of installed capacity. The energy deficit in state is 1.2% and peak load deficit is 5.6% which can be reduced by harnessing the extremely large amount of solar energy [10]. But as mentioned earlier, investment in terms of land, money and manpower is very high for such establishments. Thus, in the present study a methodology has been suggested to arrive at the optimal site selection for SPV using GIS. The advantage of this methodology is to identifying the most suitable area with minimum cost by considering criterion, as mentioned later in this paper, for any location.

2. DEVELOPMENT OF SPV SITE SELECTION MODEL IN GIS ENVIRONMENT

As mentioned earlier, there have been several works that presented different models and methodologies for the optimal selection of sites for RETs/SPV. One of the most suitable models for such an assessment is GIS based models. With its abilities to handle different kinds of topological, spatial, weather variation, GIS models offer a great advantage for the present kind of problem. The important steps in using the GIS models are (a) identifying the criteria so as to make thematic maps for the criteria that influence the site selection process (b) identifying appropriate software support that is capable of handling the identified criteria (c) building the software support in the GIS environment (d) analysis. The step by step process followed for the present problem is as explained in the following sections

2.1. Identification and Description of Criteria

A criterion is a measurable facet of a judgment, which makes it possible to illustrate and enumerate alternatives in a decision. With the inputs from various works such as, Aran [11], Adel and Yassine [3, 4], Alasdair Miller and Ben Lumby [12], 10 criteria were identified and considered. These include, amount of incident solar radiation, availability of vacant land for its present as well as for its future development, accessibility to site from highways as it affects the transportation cost and thus the initial cost, distance from transmission lines to minimize the losses. Solar PV panels works efficiently within a range of temperature which is 25^0C to 45^0C, the degradation of cells happens due to high wind velocity, extreme temperatures, shadow on modules and dusting on arrays, thus variation of local climate is significant criteria for this work. Geotechnical issues like consideration of groundwater resistivity, load bearing properties, soil pH levels and seismic risk are important criteria. Geotechnical political issues such as Site near to Sensitive military zones and historical places should be avoided. By considering Topography of site, flat or slightly south facing slopes are preferable for projects in the northern hemisphere. Efficiency of plant could be reduced significantly if modules are soiled. It is, therefore, important to consider local weather, environmental, human and wildlife factors. The criteria should include dust particles from traffic, building activity, agricultural activity or dust storms and module soiling from bird excreta. The criteria are as given in table 1.

Table1. *Criteria considered for site selection*

S.No.	Criteria
1	Availability of solar radiation
2	Availability of vacant land
3	Accessibility from national highways
4	Distance from existing transmission line
5	Variation in local climate
6	Use of nearby land
7	Topography of site
8	Geotechnical issues
9	Geotechnical political issues
10	Module soiling

2.2. Identification of GIS Software

Software which is used, to create, to manage, to analyze and visualize geographic data, (data with reference to a place on earth) is usually denoted by the umbrella term ‘GIS software’.Desktop GIS, spatial database management system, webmap servers, server GIS, web GIS, mobile GIS, software libraries and GIS extensions are some of the types of GIS softwares. But the basic requirement for this work is to have one software which can create, edit, and store, mapped, intersect and analyze the data. Thus desktop GIS used for this purpose, as it contain GIS viewer, GIS editor, GIS analyst. MapInfo, Autodesk, Bentley systems, Eredas Imagine, ESRI, IGIS, Intergraph, Small world etc.are some of the companies with high market share and providing commercial desktop GIS softwares. Among these softwares the ESRI ArcGIS 10 is most suitable because it is highly scalable server architecture. It provides data in both the raster, as well as in vector format and integrates data from multiple sources and serves it on web. ArcGIS 10 is a complete system for designing and managing solutions through the application of geographic knowledge.ArcGIS 10 has ability to automated the many aspects of cartography, it take less time as compare to other software for producing any map with better intelligence, therefore ArcGIS 10 is used as software tool in the present work.

2.3.Analysis

The criteria stated in previous section were classified on the basis of their connotation as Analysis criteria and Exclusion criteria. Analysis criteria are those which enhance the suitability of site and have positive connotation and Exclusion criteria are those which restrict the alternatives and have negative connotation as given in Table 2.The maps were generated for the analysis criteria with the help of ESRI ArcGIS 10 software. The suitable sites obtained from the intersection of all maps.Suitable sites were divided into 3 regions, further exclusion criteria were applied on each region, and the best region for site identified.The detailed discussion of Analysis methodology is taken up in the following sections.

Table2. *Classification of criteria*

ANALYSIS CRITERIA	EXCLUSION CRITERIA
Availability of solar radiation	Variation in local climate
Availability of vacant land	Use of nearby land
Accessibility from national highways	Consideration of Geopolitical sites
Distance from existing transmission line	Module soiling
Topography of site	

2.3.1. Map Generation and Application of "Analysis Criteria"

Cartographic maps had been generated with the help of ArcMap 10.0 using public maps. These inputs which were in vector format were converted into raster format and reclassified, in order to get discrete values from 1 to 9. 1 is the best of all. Thus mapping was completely normalized. The cartographic maps produced are as follows:

- *Cartographic Map of Solar Radiation*

Table3. *Discretization value of map in fig 1*

CONTINUOUS VALUE (in kWh/m^2/day)	DISCRETIZED VALUE
5.392-5.456	9
5.456-5.520	8
5.520-5.584	7
5.584-5.648	6
5.648-5.713	5
5.713-5.777	4
5.777-5.841	3
5.841-5.905	2
>5.905-5.969	1

The data of average annual solar irradiation which is available for 32 districts of Rajasthan has been taken [13]. The discretized value is given in table 3.

Fig1. *Cartographic map of Solar Radiation*

➢ *Cartographic Map of Vacant Land*

It has been obtained from the land use map of Rajasthan. Only barren, waste and vacant land were considered. According to report of EAI [14] on India solar PV advisor, the area required for crystalline silicon technology is 5 acres for 1 MW PV power plant. So the area required for 10 MW PV power plant should be50 acres(202342.821 m^2) or more.

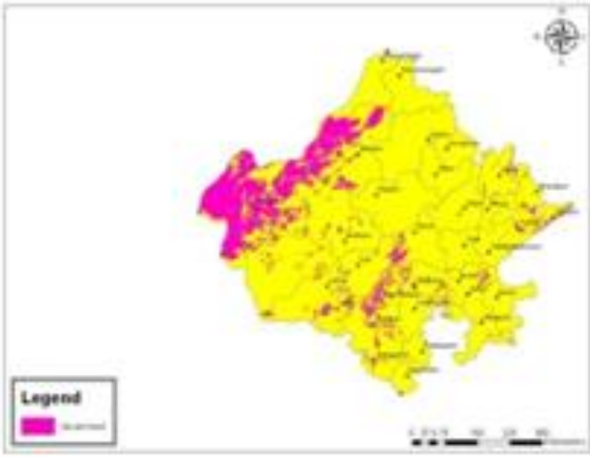

Fig2. *Cartographic map of Vacant Land*

➢ *Cartographic Map of Proximity from Transmission Line*

This map has been obtained from power map of Rajasthan. For 10 MW solar PV plant transmission line of 132kV used. And the distance of site from transmission line taken less than15km.

Fig3. *Cartographic map of Transmission Line (132 kV)*

➢ *Cartographic Map of National Highway*

This map has been obtained from the road map of Rajasthan by considering only national highways. The discretized values are shown in table 4.

Table 4. *Discretization value of map in fig. 4*

CONTINUOUS VALUE (distance from highways in kms)	DISCRETIZED VALUE
0-5	1
5-10	2
10-15	3
15-20	4
20-25	5

Fig4. *National Highway Map*

2.3.2. Application of "Exclusion Criteria"

After intersecting all maps of analysis criteria, the result showed various locations. These locations were reclassified into 3 regions namely "blue", "brown" and "green"

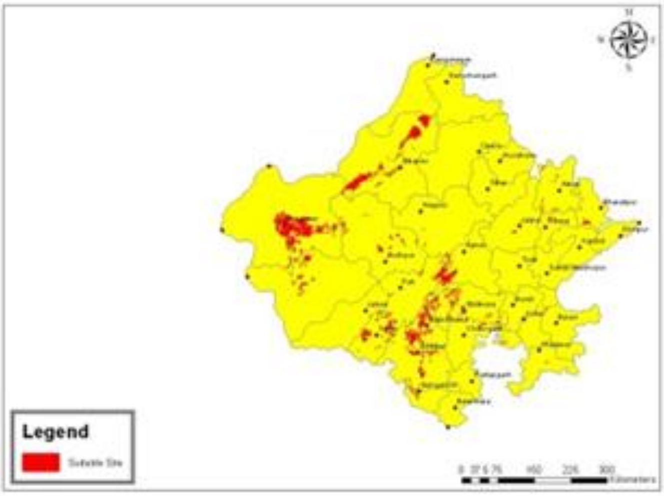

Fig5. *Intersection Map of all the cartographic maps*

"Exclusion criteria" applied on these three regions and reclassified, in order to get discrete values 1 to 9. 1 is the best of all and the most suitable region after the application of exclusion criteria

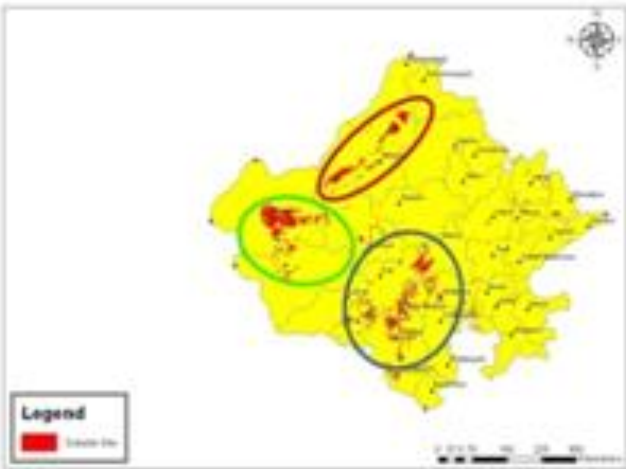

Fig6. *Reclassification of several sites into three regions*

➢ *Variation in Local Climate*

Average temperature should be in range of 25^0C to 45^0C.

Table5. *Discretization value of map in fig. 6 after application of exclusion criteria (a)*

REGION	DISCRETIZED VALUE
Blue	3
Green	1
Brown	2

➢ *Use of Nearby Land and Module Soiling*

Since Rajasthan is known for its lakes and national centuries, module soiling is an important criterion of site selection. If region is near to either urban area or natural protected area or both, it is less preferable.

Table6. *Discretization value of map in fig. 6 after application of exclusion criteria (b)*

REGION	DISCRETIZED VALUE
Blue	7
Green	1
Brown	3

➢ *Consideration of Geopolitical Sites*

The region which is situated near to international border and historical places avoided.

Table7. *Discretization value of map in fig. 6 after application of exclusion criteria (c)*

REGION	DISCRETIZED VALUE
Blue	5
Green	1
Brown	4

3. RESULT AND CONCLUSION

After applying all the criteria, "Green region" was found as most suitable area for solar PV power plant. The green region is nearby location of Jaisalmer which is situated at 26.92^0N, 70.900^0E with the maximum summer temperature of 43^0C with largest area of 180.27×10^6 m^2 in the region.

The electric power generation potential per day for the selected "Green region" can be estimated based on the calculated average annual solar radiation per unit surface area per day, the total suitable area, and the efficiency of the PV panel. Equation (1) can be used to estimate the yearly solar electric power generation potential [4]:

$$GP = SR \times CA \times AF \times \eta \tag{1}$$

Where, GP = Electric power generation potential per year (kWh/day)

SR = Annual solar radiation received per unit horizontal area (kWh/m^2/day)

CA = Calculated total area of suitable land (m^2)

AF = the area factor, indicates what fraction of the calculated areas can be covered by solar panels

η = PV system efficiency

Table8. *Generation potential of Greenregionconsidering different PV technologies*

PV Technology		Efficiency, η(%)	Maximum area of Highly Suitable land CA (m^2)	Mean annual solar radiation for highly suitable land, SR(kWh/m^2/day)	Generation potential, GP (kWh/day)$\times10^6$
c-Si	Mono Si	15-20%	180.27×10^6	5.873	111.20- 148.20
	Multi Si	15-17%			111.20-125.98
a-Si		6-9%			44.50-66.69
CdTe		9-11%			66.70-81.52
CIGS		10-12%			74.10-88.93
CPV		26.3-29%			194.90-214.92

The potential generation capacities (kWh/day) for this highly suitablelevelusing different PV technologies are presented in Table 8 [1, 15]. An area factor of AF=70% was selected based on maximum land occupancy of PV panels with minimum shading effect [15].

Optimal site analysis for large PV farms implementation was carried out for the Rajasthan of India. The results obtained from analysis of the resultant maps showed that a significant portion of land exhibits high suitability. Different PV technologies were considered for implementation and it was found that CPV technology provides very high technical potential for implementing large solar plants.Through this study we have demonstrated the ease with which one can use GIS software and the many possibilities allowed thanks to its numerous tools and extensions. The results have been very positive and give an idea of the validity of the method since solution location i.e. “Green region” is found equivalent to a real SPV plant proposal of the DhirubhaiAmbani Solar Park at Dhursar village near Pokran in the Jaisalmer district of Rajasthan. Finally, this work left open an important research field in the general topic of application of GIS to solving problems related to renewable energy and, in particular, in the subject of SPV plants.

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