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Exploring potential for solar photovoltaic Park: A case study on Madhya Pradesh state of India

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Abstract

The present study is focused to prioritize the districts of the state of Madhya Pradesh in India, and find out district wise potential for solar PV Park. The study also investigates to set up large solar PV grid connected power plant. Index has been developed using six parameters; Global horizontal irradiance (C_1), Clear sky insolation (C_2), Waste land (C_3), Land cost (C_4), Availability of grid (C_5) and Availability of local infrastructure (C_6). Subsequently districts of the state have been ranked based on their relative position. The weight of various parameters is determined by analytical hierarchy process (AHP). The ranks are found by applying technique for order of preference by similarity to ideal solution (TOPSIS) method by collecting district wise primary and secondary data of all parameters from various sources. The availability of solar irradiance, clear sky insolation and waste land are found to be most weighted parameters. This study may prove useful for investors and policy makers to increase the investments in solar power sector in the Madhya Pradesh state of India for a sustainable development.

Keywords: Solar PV Park, Grid, AHP, TOPSIS;

1. Introduction

After the Kyoto Protocol recently held COP also known as Paris climate conference 2015, most of the developing and developed countries have agreed to cut carbon emission levels to reduce the greenhouse gases [1]. Developing countries like India have to balance its climate and developmental priorities [2]. So it is the responsibility of both the central and state government to cut emission level and develop clean energy sources. Solar energy in India as on 25th May 2012 was 2.6 GW, whereas during the same time Germany had close to 22 GW, however India has 9.2 times greater land than Germany. Both central and state government have exponentially increased their solar target and fixed it at 100GW by 2022. In Reinvest Global Summit held in India in February 2015 companies made commitment to invest in building capacity equal to 166GW solar power [3].

Due to availability of solar resources there is huge scope for expanding solar energy in India [4]. The Jawaharlal Nehru National Solar Mission was launched in 2009 which targeted 22000 MW grid connected solar energy by 2022 [5]. Madhya Pradesh is located in the center of India and has very low human development index (HDI). Being a part of BIMARU states (Bihar, Madhya Pradesh, Rajasthan and Uttar Pradesh), it has far more developed than its counterparts in various sectors like industry, energy etc. A reason for this may be its strategic location and availability of raw material. The state domestic product grew at 10.3% in during the period 2007-13 whereas India's GDP grew at 7.15% in same period [6]. The state has developed a good capacity of installed energy but still 12% of the state population has no access to electricity [7]. MP has good solar radiations and availability of waste land, so it has become prime choice for energy investors. The state had total grid connected solar power of 37.32 MW as on 31st March 2013 and further grew to 347.17MW during March 2014 registering a growth rate of 67.49%,which was highest of all states in India [8]. In grid connected power, MP stands at 3rd position as shown in table 1 [8]. Energy production cost is found to be less in Bhopal region of central and eastern India as compare to other region [9].

With the availability of more than 3000 hours of solar radiation every year [10], Madhya Pradesh stands at 3rd position in the solar energy resource potential in India after Gujarat and Rajasthan [11,12] as shown in Table.1. The state has large waste land with 19.4% of the total area whereas net sown area is 48.91% of the total area of which 43.25% is irrigated [1314]. Therefore, the state has a huge potential for developing solar park or large PV power plant which requires huge land availability and investment. Due to availability of large non-irrigated land, there is possibility of getting leased land at low cost and long term. With increased use of solar PV panel and mass production, there has been a trend of reducing cost of PV panels and technology in the recent times [15] but the cost of land still remains a concern as land requirement for PV plant is 7-8 acres per MW which is quiet high [16]. In this context, this study employs six parameters which are essential in setting large scale grid connected power plants. The study has been organized as follows:

1) Identifying and determining various parameters essential for setting solar park.
2) Predict weightage of all parameters.
3) Collecting primary and secondary data from various sources for all 50 districts in MP state of India.
4) Ranking all districts on the basis of solar potential to set up a solar park or grid connected large power plant.
5) Conclusion and recommendations.

Table.1 Capacity wise ranking of BIMARU states.

State	Capacity (MW)	Rank
Gujarat	916.40	1
Rajasthan	730.10	2
Madhya Pradesh	347.17	3
Maharashtra	249.25	4
Andhra Pradesh	131.84	5
Tamil Nadu	98.36	6

The literature review reveals that various researchers have used different tools in different fields. Singh et al. [11] used AHP and TOPSIS method to find out solar energy potential of eleven states India. On the other hand Choudhary and Shankar [17] employed the FAHP and TOPSIS methods to evaluate and find the best location for thermal power plants. Metin et al. [18] used AHP to assign weightage to various parameters of weapon system and TOPSIS to rank the weapons. Amiri [19] selected project of oil fields by giving weights to various parameters using AHP and then ranked the projects with the help of TOPSIS. Umran et al. [20] applied fuzzy TOPSIS multi criteria decision method (MCDM) to rank the various renewable energy supply systems in Turkey. Taylana et al. [21] used Fuzzy AHP and Fuzzy TOPSIS to select location of construction project and evaluated the risks present in dynamic environment. Senthila et al. [22] evaluated and selected of reverse logistic operating channel in fuzzy environment. Qureshi et al. [23] applied the methods of Fuzzy AHP and TOPSIS for the selection of third party logistic provider. In another study, optimum maintenance policy in a textile firm is selected using AHP and TOPSIS methods in fuzzy environment [24]. Ref.[25] applied AHP method for selection of green energy sources. In study [26] AHP was applied to find out best renewable energy resources, whereas [27] used the AHP technique to evaluate significant renewable energy resources in India. In Thailand [28] used fuzzy AHP and TOPSIS method for selection of solar power plant location. In study [29] the fuzzy TOPSIS method was used for the selection of optimal site for charging of electric vehicles. On the other hand [30] used the AHP method for selection of solar investment projects. In Istanbul, [31] used fuzzy AHP to calculate weights of various criteria and TOPSIS to find out best site for shopping mall in the city.

2. Problem identification and basic principle

Parameter selection

Based on literature survey, six parameters were identified that significantly influence the decision for setting a large PV power plant or solar parks. These six parameters can be broadly classified into three broad categories namely; availability of solar energy, land and infrastructure. Further, the parameter of availability of solar energy is divided into two parameters; global horizontal irradiance and clear sky insolation, land is divided into; availability of waste land and land cost, whereas infrastructure is divided into; availability of grid with metering facility and local infrastructure in the district.

Global horizontal irradiance (C_1): Solar radiation is the most essential parameter for efficient performance of the solar plant. The amount of solar energy is calculated by global horizontal irradiance (GHI) .GHI data has been collected from NASA website [27]. It is 22 years monthly average of the total solar radiation incident on a horizontal surface and calculated in kWh/m^2/day. Most of the previous studies have taken GHI as a parameter for solar power plant site selection like [11, 30, 32 and 33].

Clear sky insolation (C_2): The amount of solar energy highly depends upon the weather of the area like cloudiness [34]. Many researchers like [35 & 36] have taken insolation as a location selection parameter. So to determine the stability of the solar radiation clear sky insolation data is also collected from NASA by entering longitude and latitude of each district [27]. It is monthly averaged data of 22 years which is the total solar radiation incident on a horizontal surface at earth when the cloud cover is less than 10% and calculated in kWh/m^2/day.

Waste land (C_3): Land availability is also a major factor to find out best areas to locate mega solar power plant or solar parks. Land acquisition is also a major problem in India [37]. Waste land can be utilized to set up solar PV plant as this requires huge land as compared to other power plants. Solar energy potential in western ghat is calculated using 5% of waste land [34]. Availability of barren uncultivable land in Madhya Pradesh makes it solar hotspot in India [38 & 32]. Waste land district wise data is collected from waste land atlas of India and government of MP report on agriculture [13 & 14]. Waste land is taken without forest and wildlife habitat and 10% of the total waste land is used to compute indices in order to avoid factors like slope, flooded region etc.

Land cost (C_4): Land cost has a direct impact on investment. Higher cost of land increases the project cost [33]. High initial capital cost is found to be the main barrier in implementing solar project [37,39]. In order to decrease the payback period and hence reduce the overall cost of the project, land cost plays a major role. In present study, land cost is approximated by land holding per rural person as suggested by [40, 41 & 42]. If land holding per rural person increases, the cost of land decreases. It shows the spread of rural population. Data for district wise total rural land population is collected from Indiastat. It is calculated by dividing district wise total rural land with total rural population.

Availability of grid (C_5): Solar parks or large PV power plants require grid with metering facility to supply the power. A power line and grid in proximity of the site is a positive factor in selection which leads to less transmission losses [30]. Delay in plant operation can be avoided if there is a grid nearby. As per MP government's solar policy, it is the responsibility of solar plant to layout line to nearest grid [12]. So district wise total number of interconnection points (132 kv and above) with metering facility data was collected.

Availability of local infrastructure (C_6): Lack of local infrastructure is the biggest problem for solar power installation in India [37]. Availability of town is a good indicator of the infrastructure of a particular district. Basic amenities like school, police station, market, labor availability is essential for smooth running of a plant. Most of the towns also have electric grids and are well connected by state highways. Parameters taken by [43 & 44] like distance from urban area and roads will be less in a district which has more number of towns. Town population can be benefitted from solar power and transmission losses will be less [1 & 33]. Therefore district wise data was collected on number of towns. All towns are well connected by roads which are essential to access the site for solar plant.

	C_1	C_2	C_3	C_4	C_5	C_6
C_1	1					
C_2	.213	1				
C_3	-.464**	.072	1			
C_4	-.029	.259	.247	1		
C_5	.331*	-.037	-.268	-.338*	1	
C_6	.081	.018	.043	-.280*	.562**	1

* correlation is significant at the 0.05 level

** correlation is significant at the 0.01 level

3. Methodology

Analytical hierarchy process: AHP was introduced by Saaty in 1980 to determine the relative importance of various activities [18]. AHP is used in complex decision making and it is widely used as a strategic decision making tool by top management [11]. AHP can be employed on both quantitative and qualitative data, but the main disadvantage is that a large number of pair wise comparison are required if the number of alternatives increases. Since AHP uses discrete number scale of (1-9), hence it can make ambiguities in results about weight of different parameters [17]. Therefore, problem is broken down in several steps and presented in the form of hierarchy [30]. Fuzzy AHP is an extension of AHP and is applied to get more accurate decision by prioritizing the criteria of selection and giving weights in unclear environment [31]. Many fuzzy AHP applications are used in the literature for selection of alternatives in MCDM environment. For calculating the fuzzy AHP, [19 & 27] proposed AHP pair-wise comparison based on numeric value (Table.2) assigned on a scale of 1-9 to the attributes.

Table. 2 Intensity of scale in AHP.

Importance of number	value
Both parameters are equally important	1
One parameter is moderately more important than other	3
One parameter is strongly more important than other	5
One parameter is very strongly more important than other	7
One parameter is extremely more important than other	9
Importance between these numbers	2,4,6,8

Let C = {C_j Ij=1,2,3…….n} be a set of criteria taken in study. The evaluation matrix A of the order of (n*n) can be formed by using pair-wise comparison of criteria in which every element b_{ij} (ij=1,2,3,……..n) is the quotient of parameter weight, which is as shown

$$\boldsymbol{B} = \begin{vmatrix} \boldsymbol{b11} & \boldsymbol{b12} & \dots & \boldsymbol{b1n} \\ \boldsymbol{b21} & \boldsymbol{b22} & \dots & \boldsymbol{b2n} \\ \boldsymbol{bm1} & \boldsymbol{bm2} & \dots & \boldsymbol{bmn} \end{vmatrix}$$

where $b_{ij=}1$, $b_{ji}=1/b_{ij}$,$b_{ij}\neq 0$

At last the mathematical process is carried out for normalization of above matrix and relative weight of each matrix is calculated. The relative weights are given by the right eigenvector (w) corresponding to the largest eigen value (λ_{max})as:

$B_w= \lambda_{max}W$

The weights can be found by normalizing any of the rows or the columns of matrix if the pair-wise comparisons are completely consistent. The suitability of the output of AHP can be found by checking the consistency of pair-wise comparisons. The consistency is defined as the relation between the entries of B: $b_{ij}\times b_{jk}= a_{ik}$

The consistency of the system can be used to check whether evaluation is sufficiently consistent. The consistency can be found by the consistency ratio (CR):

CR=CI/RI ………………..(1)

The CR value should be less than 0.10. If not, then the procedure of AHP must be reviewed to enhance consistency. CI is the consistency index which can be expressed as

CI= (λ_{max-n})/(n-1) …………………(2)

Here RI is the random index of consistency and has predefined value.

TOPSIS

The technique of order performance by similarity to ideal solution (TOPSIS) was first developed by Hwang and Yoon [18]. According to TOPSIS method, best ideal solution is found which is nearest to positive ideal solution and farthest from negative ideal solution. The following steps are used in TOPSIS [28]:

Step 1: construct the normalized decision matrix, the row values (x_{ij}) are transformed in to normalized value (y_{ij}) using the formula

$Y_{ij}=x_{ij}/\sqrt{\sum_{i=0}^{m} x_{ij}}^2$ i =1,2……….m; j = 1,2……n

Step 2: calculate the weighted normalized matrix and its values (v_{ij}) are given by the equation

$V_{ij} = w_j n_{ij}$

where i =1,2……….m; j=1,2……n

Where w_j is the weight of j^{th} criteria and $\sum_{j=1}^{n} wj=1$

Step 3:determine the negative(A^-) and positive ideal solution(A^+) $A^+ = \{v_1^+,……..,v_n^+\} =\{[\max v_{ij} \mid i \in I], [\min v_{ij} \mid i \in J]\}$.

$A^- = \{v_1^-,……., v_n^-\} =\{[\min v_{ij} \mid i \in J], [\max v_{ij} \mid i \in I]\}$

Where v_i^- denotes the minimum value and v_i^+ denotes the maximum value of v_{ij}

Step 4: calculate the separation from positive ideal solution

$D_i^+=\sqrt{\{\sum_{j=0}^{n} (v_{ij}-v_j^+)^2\}}$

Where; i =1,2,……..,m ………………….(3)

similarly calculate the separation from negative ideal solution

$D_i^-=\sqrt{\{\sum_{j=0}^{n}(v_{ij}-v_j^-)^2\}}$

Where ,i =1,2,……..,m …………………..(4)

Step 5: calculate the closeness coefficient of each alternative and rank the alternatives

$C_i = D_i^-/(D_i^+ + D_i^-)$

where i=1,2,………..,m ……………………….(5)

5. Results and discussions

This study aims to find out potentiality index for set up of solar park or a large solar PV power plant from availability of various resources view point. Various districts of state of Madhya Pradesh are ranked based on crucial factors. The six criteria taken are; global horizontal irradiance (C_1), clear sky insolation (C_2), waste land without forest (C_3), land holding per rural person(C_4), availability of power grid (C_5) and availability of infrastructure (C_6).

The results obtained from pair-wise comparison matrix are presented in the Table 3. Consistency ratio as shown in Table.4, is calculated as 0.073 using equation (1) which is less than 0.10. Hence, the calculated weights can be used in TOPSIS ranking process [18].

Table.3 Criteria matrix (pairwise comparison).

	C_1	C_2	C_3	C_4	C_5	C_6
C_1	1	1	1	1	3	5
C_2	1	1	1	1	3	5
C_3	1	1	1	1	3	5
C_4	1	1	1	1	1	1
C_5	1/3	1/3	1/3	1	1	3
C_6	1/5	1/5	1/5	1	1/3	1

Table.4 Results obtained with AHP.

Criteria	weight	λ_{max}	CI	RI	CR
C_1	0.224	6.45	0.091	1.24	0.073
C_2	0.224				
C_3	0.224				
C_4	0.161				
C_5	0.104				
C_6	0.063				

Evaluation of criteria and determination of final ranking of districts

Evaluation of criteria is done using TOPSIS method. Separation from negative ideal solution and positive ideal solution is calculated using equations (4) and (3). Closeness coefficient is calculated using formula (5) and various districts are ranked as per score of closeness coefficient. The maximum value of C_i is 0.771 and minimum value is 0.120. The results of TOPSIS calculation are shown in the Table 5.

6. Conclusions

Present study uses the TOPSIS technique of multi criteria decision making (MCDM) approach to construct potentiality index for better exploitation of available resources for solar power plant of various districts of Madhya Pradesh state of India. Six parameters were identified from technical and economical point of view. These parameters were weighted using AHP, and reveals that; Global horizontal irradiance (C_1), clear sky isolation (C_2) and waste land (C_3) are found to be most influential parameters while availability of local infrastructure (C_6) is found to be least influential. The results of TOPSIS method applied on the secondary data of various criteria and potentiality index of various districts revealed that. Chhatarpur, shivpuri, Betul, Panna and Satna districts are found as the top scoring districts and these districts could prove to be best options to set up a large PV power or develop solar park plant. Contrary to it, Alirajpur, Burhanpur and

Datia, are found to be at the bottom of the ranking. This study may prove useful for state government to examine and evaluate its current policies on solar energy and locating the sites for solar parks in future. The findings may also be helpful for the solar energy investors to find out most potential site for large grid connected solar power plant in the state of Madhya Pradesh. Further research can be done by employing more parameters and different weight assignment techniques.

Table 5. Ranking obtained from TOPSIS.

Districts	D_i^-	$(D_i^+ + D_i^-)$	C_i	Rank
Sheopur	0.043	0.053	0.447	12
Morena	0.025	0.066	0.271	30
Bhind	0.017	0.073	0.184	43
Gwalior	0.029	0.059	0.329	22
Datia	0.014	0.074	0.158	48
Shivpuri	0.074	0.028	0.724	2
Tikamgarh	0.034	0.059	0.364	18
Chhatarpur	0.084	0.025	0.771	1
Panna	0.058	0.039	0.598	4
Sagar	0.033	0.066	0.336	20
Damoh	0.024	0.071	0.257	32
Satna	0.057	0.042	0.578	5
Rewa	0.027	0.064	0.299	27
Umaria	0.029	0.060	0.328	23
Neemuch	0.022	0.070	0.235	37
Mandsaur	0.021	0.071	0.227	38
Ratlam	0.015	0.074	0.164	47
Ujjain	0.023	0.074	0.241	35
Shajapur & Agar Malwa	0.024	0.074	0.246	34
Dewas	0.022	0.079	0.215	39
Dhar	0.025	0.071	0.263	31
Indore	0.030	0.070	0.299	26
West Nimar(Khargone)	0.028	0.061	0.312	25
Barwani	0.015	0.076	0.169	46
Rajgarh	0.030	0.061	0.331	21
Vidisha	0.022	0.070	0.240	36
Bhopal	0.017	0.077	0.184	42
Sehore	0.023	0.069	0.254	33
Raisen	0.027	0.072	0.271	29
Betul	0.059	0.030	0.666	3
Harda	0.017	0.080	0.174	45
Hoshangabad	0.033	0.058	0.360	19
Katni	0.046	0.045	0.506	10
Jabalpur	0.034	0.058	0.369	17
Narsimhapur	0.018	0.071	0.199	40
Dindori	0.042	0.055	0.437	15
Mandla	0.039	0.050	0.439	14
Chhindwara	0.049	0.040	0.549	8
Seoni	0.050	0.042	0.542	9
Balaghat	0.034	0.053	0.391	16
Guna	0.052	0.038	0.576	6
Ashoknagar	0.024	0.064	0.273	28
Shahdol	0.053	0.040	0.569	7
Anuppur	0.041	0.047	0.465	11
Sidhi	0.028	0.060	0.320	24
Singrauli	0.040	0.050	0.442	13
Jhabua	0.016	0.073	0.178	44
Alirajpur	0.011	0.081	0.120	50
East Nimar(khandwa)	0.018	0.075	0.196	41
Burhanpur	0.014	0.083	0.144	49

Abbreviations: AHP, TOPSIS, MCDM, PV

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The 1st International Conference on Energy, Environment and Economics (ICEEE 2016) was held at Heriot-Watt University, Edinburgh, EH14 4AS, UK, 16-18 August 2016. ICEEE2016 focused on energy, environment and economics of energy systems and their applications. More than fifty eight delegates from 31 countries with diverse expertise ranging from energy economics, solar thermal, water engineering, automotive, energy, economics and policy, sustainable development, bio fuels, Nano technologies, climate change, life cycle analysis etc. made conference true to its name and completely international. During conference total 51 oral presentations and six posters were shared between delegates. The presentations showed the depth and breadth of research across different research areas ranging from diverse background. ICEEE2016 aimed:

- To identify and share experiences, challenges and technical expertise on how to tackle growing energy use and greenhouse gas emissions and how to promote sustainability and economical, cost effective energy efficiency measures.

In total 11 technical sessions and two invited talks both from academia and industry provided insight into the recent development on the proposed theme of the conference. Preparation, organisation and delivery of the conference started from July 2015 and further co-ordinated by vibrant team of Conference Centre, Heriot Watt University. Conference organisers would like to acknowledge support from the sponsors particularly World Scientific Publication ltd and its team members for the delivery of the conference. Organisers are also thankful to all reviewers who contributed during peer review process and their contributions are well appreciated. At the end and during vote of thanks following awards have been announced and we would like to congratulate all well deserving delegates.

- Best Paper –Academia: Amela Ajanovic, EEG, TU Vienna, Austria
- Best Paper – Student : Christian Jenne,University of Duisburg-Essen, Germany
- Best Poster – Student: Yoann Guinard, University of New South Wales, Sydney, Australia
- Best Poster – Academia: E. Salleh, Universiti Kebangsaan Malaysia, Malaysia
- Active Participation Award - Yoann Guinard, University of New South Wales, Sydney, Australia

At the end we would like to extend our gratitude to all of you for your participation and hopefully welcome you again during ICEEE2017.

Editors:
Dr. Singh is Senior Scientist at Indian Agricultural Research Institute, New Delhi, India. Her area of expertise are bio energy and bio fuels, environmental engineering, carbon accounting and renewable energy integration for rural development.
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