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Energy Efficient Grid Management Using Geographical Information System (GIS): a Case Study for Western Gujarat

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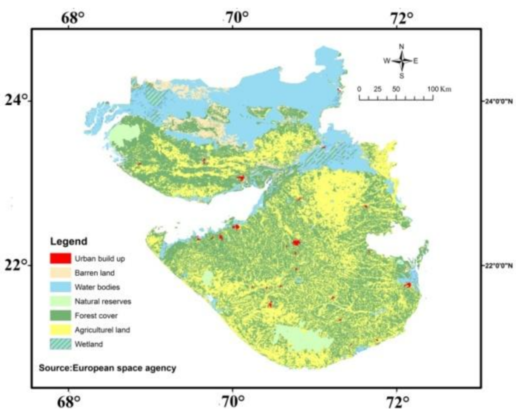
Abstract: *Present study focuses on the assessment of geographical, environmental and economical criteria of the western part of Gujarat state of India, governing deployment of solar energy as a distributed source of generation as a potential solution to reduce grid losses and increase efficiency of the western grid. During current study, urban and industrial settlements are treated as bulk consumers of power and their distance from generating station as major contributor to transmission and distribution losses (T&D losses). An analytic framework is developed by the authors based on Geographical Information System (GIS). This framework includes different parameters like water bodies, agricultural land, forest cover, natural reserves, wetlands etc. Important economical parameters like proximity of suggested locations from the point of generation and consumption, the distance from the cities and industrial areas, solar radiation potential are also considered. Further, fuzzy logic is applied to address different parameters under study to identify the best possible sites in terms of overall acceptance, which are not only the best receptor of solar radiation but also the optimal sites for distributed generation to minimize the losses and thereby enabling energy efficient grid management for western grid of Gujarat.*

Key Words: *Photovoltaic technology, Solar energy, GIS,T&D losses, Energy efficiency, Grid management, Fuzzy logic, Irradiance, Distributed sources of energy*

I. Introduction

Gujarat has one of the largest and most reliable electricity transmission and distribution network (grid) comprising many generating stations (power plants) at different locations. The study area of Saurashtra and Kutch region are shown in figure 1 catered by Paschim Gujarat Vij Company Limited (PGVCL).

Figure 1 Land use map of western Gujarat: Depicting urban build-up area, barren land, water bodies, natural reserves, forest cover, agricultural lands, wetlands etc.



While on one hand PGVCL has the largest number of customers, and on the other hand, it has reported the largest distribution losses of 34-35% for the year 2009-10[1]. Further, GETCO has reported 4% of loss on account of transmission losses in the state [2]. Decentralized solar photovoltaic (PV) power plants installed on utility scale, can act as a distributed source of generation and can reduce the grid losses to a significant amount [3,4]. We have discussed and demonstrated the method of selecting key locations where if solar PV power plants are installed they can act as distributed source of generation and reduce losses in transmission and distribution grid with the help of geographical information system (GIS) and fuzzy logic.

It has been assumed that urban and industrial areas are bulk consumer of power. Further it is assumed that they have well established transmission network which is the prime requirement of grid connected power plants. However, many environmental and economical factors restrict the usability of land for solar PV installations [5].

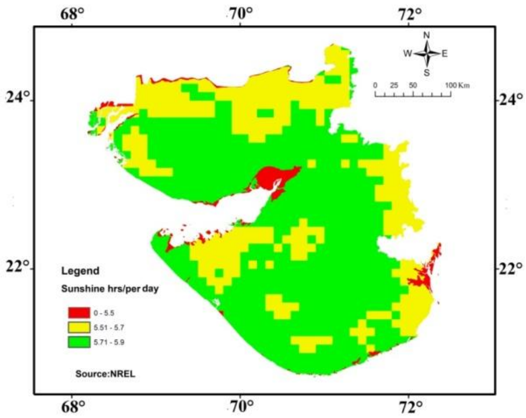
Regions suitable for tapping solar energy are mapped based on global solar is radiation data, that provides a picture of the potential. Fields without vegetation (barren or wasteland) are most preferred locations for PV systems. Finally these locations are proposed for installation of solar PV plants.

II. Methodology

A. *The Data*

Solar potential atlas for Gujarat is acquired from National Renewable Energy Laboratory (NREL) [6] and presented in figure 2.

Figure 2 Solar potential map over western Gujarat: showing a range of sunshine hrs/day in three classes.



Solar energy potential atlas provides solar irradiation information of the study area. Sub-stations locations are acquired from M/s. GUVNL Ltd., Baroda. Industrial location map is acquired from the maps of India (www.mapsofindia.com) [7] in point shape file format. The vector data i.e. urban and city areas, wetlands, natural reserves, water bodies, forest cover, agricultural lands information are mapped from land use/land cover map obtained from European Space Agency (ESA) [8]. All these data are converted to 2 km X 2 km grid. Other data such as taluks and district boundaries are obtained from Diva gis [9]. All these data are transferred into shape file and converted to 2 km X 2 km grid and processed as fuzzy sets in GIS in order to obtain spatial data layers. Here the solar potential, urban areas, sub-stations and industrial locations are grouped as '**economical factors'**. Similarly, wetlands, natural reserves, water bodies, forest cover and agricultural lands are grouped as '**environmental factors'** and shown in table 1.

B. *Fuzzy Logic*

Most Fuzzy sets are used to represent the criteria or objectives that do not have crisp boundaries usually due to non-availability of information about the criteria or objectives. Fuzzy sets also include crisp (precise) sets that are characterized by membership functions. For a crisp (precise) set A, an element x in the universe is either a member of the set A (=1) or not (=0) like a binary number. Mathematical function of this binary membership can be represented as

$$X_a(x) = \begin{cases} 1, & x \in A \\ 0, & x \notin A \end{cases}$$

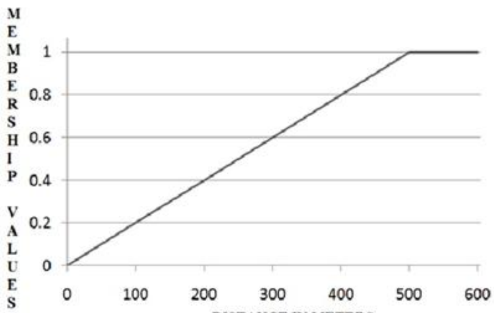
Where $X_a(x)$ indicates an explicit membership of an element x in set A and the symbol $\in$ indicates the data is 'contained in' and the symbol $\notin$ indicates that the data is 'not contained in'. The membership value '0' indicates no membership and the value '1' indicates full membership similar to that of a crisp set. Thus if the value of membership is unity means higher grade of membership and zero or nil means the data doesn't exist. The difference between the crisp and fuzzy set is that an element in a set of universe can be represented by an infinite number of values between the value '0 and '1' in fuzzy sets, while it can only be represented by '0' or '1' for the crisp sets [10].

The degree of compatibility of the location with respect to each of the factor- environmental and economical- is determined by using the membership functions of the fuzzy sets associated with one of this factor [5]. The degree of compatibility is referred to as the individual satisfaction degree. For example in figure 3, the distance of environment factor (water body) is shown as a function of membership value. It the water body is very close, then the membership value is '0' and if it is more than 500 m, the value is '1'. The membership value varies from 0 to 1, depending on the distance as shown in figure 3.

Table 1- Factors considered environmental and economical factors taken into consideration for computing individual satisfaction degrees and represent them as fuzzy sets.

Factors	Criteria
Wetlands	Minimum distance 5.5 km
Natural reserves	Minimum distance 1.5 km
Water bodies	Minimum distance 500 m
Forest cover	Minimum distance 1.5 km
Agricultural lands	Minimum distance 1.5 km
Solar irradiation(GHI)	Minimum 5.5 Sunshine Hrs/day
Urban areas	< 5 km
Sub-stations	< 5 km
Industries	< 5 km

Figure 3 Fuzzy set for 'acceptable in terms of water bodies': the membership values varies from 0 to 1 depending on the distance



C. *"AND" Operator*

In fuzzy logic there are various operators as per the requirement of the problem such as 'OR', 'AND','SUM', 'NOT' etc. In the following, more details are provided on 'AND' operator as we have used this operator in our present study. The 'AND' operator helps the decision makers, to make decisions based on the satisfaction with many criteria. For a situation of two or more criteria to be considered T-norm operators is a useful parameter. T-norm operators enable implementation of fuzzy set aggregation. It is noted by Yager (1996) [11] that T-norm is a way to find Pareto optimal solution, because of its monotonic properties. In other words, if one of the parameter has a zero satisfaction degree, the evaluation of overall satisfaction returns to zero, For instance, if the decision maker wants to consider many parameters with different criteria and satisfy all of the 'n' criteria, $\overline{F_i}$, $i = 1,....,n$, then this can be represented by:

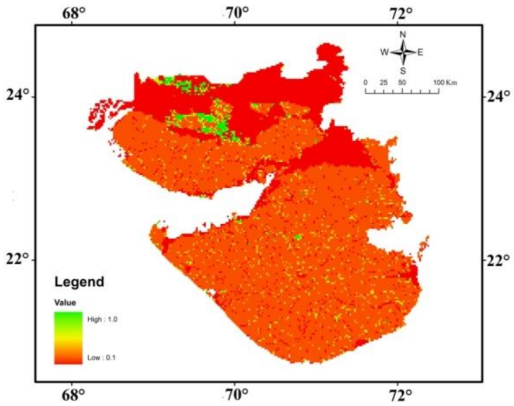
$$D = \overline{F_1} \cap \overline{F_2} \dots \cap \overline{F_n}$$

D is the overall satisfaction and the bar sign on capital letters $\overline{F_1}$ $\overline{F_2} \dots \overline{F_n}$ represent fuzzy sets. The following theorem expresses the important property of T-norm operator. Considering 'T' corresponds to the T-norm operator, then for any value of criteria a and b such that $T(a, b) \leq Min(a, b)$. Implementation of 'AND' operator allows no compensation for one bad satisfaction (MCDM) in multi criteria decision making [12].

D. *Computation of Individual Satisfaction Degrees*

Membership functions associated with environmental objectives and economical feasibility criteria are used to compute individual satisfaction degrees of each alternative location and represent them as fuzzy sets in GIS environment. Individual satisfaction degrees are calculated by using the previously stored data in the related layers. The individual satisfaction degrees are recorded in a separate column in the GIS database. The next step is to aggregate these individual satisfaction degrees into an Environmental Performance Index (EPI) as shown in figure 4 and SEPI as shown in figure 5 using multi-criteria decision making (MCDM).

Figure 4 Environmental performance index (EPI): which is satisfying most of the environmental objectives and is showing potential sites within the range value of 0.1 to 1

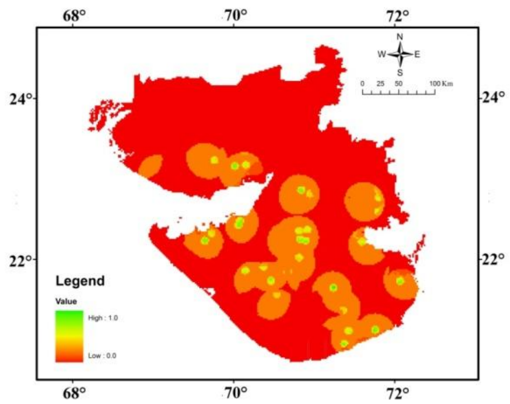


E. Multi-Criteria Decision Making (MCDM)

Using MCDM evaluation of a set of alternatives is possible with respect to conflicting and incommensurate criteria. A criterion is a generic term includes both the concepts of attribute and objective as clearly mentioned in the literature [13]. When the standardization of criteria is represented by fuzzy measures, the MCDM concerns the aggregation of multiple measures into a single statement that corresponds to the final degree of suitability. In this study, the Environmental Performance Index (EPI), is shown in figure 4, satisfying most of the environmental objectives and Solar Energy Performance Index (SEPI), is shown in figure 5, satisfying most of the economical feasibility criteria.

These results can be considered as the pre-final degrees of suitability. The final degree of suitability is the overall performance index (OPI), based on both the above criteria. This is achieved and shown in figure 6. Priority sites are identified using the following decision criteria. The sites with an OPI of 0.5 or higher are the suitable locations for solar energy generation facilities in terms of both environmental and economical feasibility criteria.

Figure 5 Solar energy performance index (SEPI): which is satisfying most of the economical feasibility criteria and is showing potential sites within the range value of 0 to 1

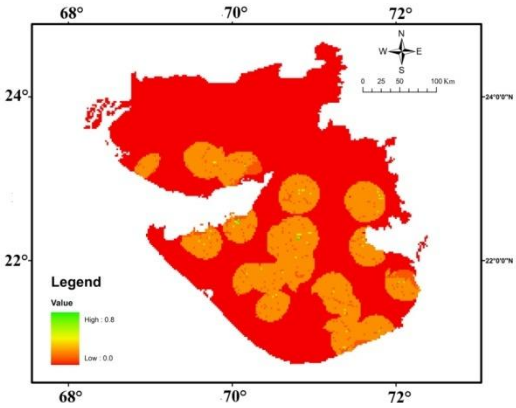


III. Results

The aim of our study is to consider the two parameters, namely, environment and economic factors. The environment parameter for suitability of PV plants is first considered. Suitable location appears to be in the northern part of Kutch district and some small pockets scattered over the whole study area – western part of Gujarat - as shown in figure 4. Next, the economic factor for suitability of PV plants is presented considering four parameters namely the solar irradiation, proximity of sub-stations, urban areas, and industrial centers. Our analysis indicates southern part of Kutch and parts of Saurashtra seems to be the preferred locations, as shown in figure 5. As can be seen, in the region of Saurashtra, mainly the Rajkot and the Amreli districts are appeared to be the most preferred locations. The threshold value considered, as described earlier is 0.5.

Accordingly, in figure 6, the preferred location for installation of PV plants is prepared by combining the two parameters again with a threshold value of 0.5. The total number of locations is about 36 and located mostly over Rajkot and Amreli districts and small pockets within Surendranagar, Bhavnagar, Jamnagar, Kutch and Junagadh districts.

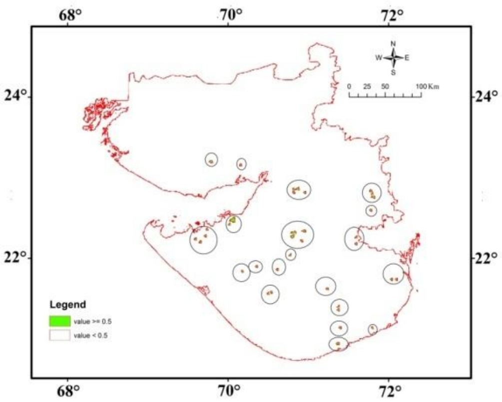
Figure 6 Overall performance index (OPI): which satisfies both environmental objectives and economical feasibility criteria and is showing potential sites within the range value of 0 to 0.8



IV. Results and Discussion

Geographical Information System (GIS) is effectively used as a tool to provide an optimal solution to energy efficient grid management. Finally, the priority sites with a 0.5 threshold value were identified, which are appearing as green patches and marked with black circles (for clarity) as shown in figure 7.

Figure 7 Overall performance index (OPI): which satisfies both environmental objectives and economical feasibility criteria and is showing potential sites within the range value of 0 to 0.8



It is known that 1 MW PV plant requires approximately 5.3 acres of area. On this basis, the area of the potential sites can be calculated from which the size of PV plants can be computed. The details of these findings and their description are presented in table 2.

Table 2: Geographical details and installation capacity over priority sites.

S.No.	place (talukas)	x (longitude)	y (latitude)	area (in acres)	possible installations (in MW)
1	Bhuj	69.79	23.20	1521.01	287
2	Anjar	70.16	23.16	771.62	145
3	Morbi	70.82	22.86	772.59	145
4	Morbi	70.87	22.86	1523.16	287
5	Lakhtar	71.78	22.84	772.65	145
6	Morbi	70.82	22.82	772.72	145
7	Morbi	70.96	22.82	772.72	145
8	Lakhtar	71.80	22.80	772.78	145
9	Lakhtar	71.81	22.76	1523.80	287
10	Limbdi	71.78	22.60	773.44	145
11	Jamnager	70.06	22.47	5545.20	1109
12	Jamnager	70.02	22.42	774.04	146
13	Khambhaliya	69.74	22.36	774.24	146
14	Rajkot	70.95	22.34	1526.55	288
15	Rajkot	70.82	22.32	2266.79	428
16	Khambhaliya	69.72	22.28	774.51	146
17	Rajkot	70.80	22.27	2478.94	467

18	Botad	71.60	22.26	774.58	146
19	Khambhaliya	69.60	22.24	774.64	146
20	Rajkot	70.92	22.22	774.71	146
21	Khambhaliya	69.66	22.20	774.78	146
22	Botad	71.60	22.18	774.85	146
23	Gondal	70.78	22.04	775.33	146
24	Jam Kandorna	70.36	21.90	775.81	146
25	Jetpur	70.62	21.86	775.95	146
26	Upleta	70.18	21.84	776.02	146
27	Bhavnager	72.04	21.74	776.37	146
28	Bhavnager	72.10	21.74	776.37	146
29	Amreli	71.24	21.62	776.79	146
30	Junagarh	70.54	21.58	776.93	146
31	Junagarh	70.50	21.56	777.00	146
32	Kundla	71.38	21.40	777.57	146
33	Kundla	71.38	21.36	777.71	146
34	Kundla	71.40	21.14	778.51	146
35	Mahuva	71.80	21.14	778.51	146
36	Jafarabad	71.37	20.94	1536.27	289
	Cumulative			39625.44	7523

From our study, the total solar PV installation potential for Gujarat, considering the stringent environmental and economic factors based on the existing infrastructural facility, will be about 7500MW.

V. Summary and Conclusion

Identification of consumption points and resources requires study of complex relations amongst many environmental and economical factors which can restrict the resource availability. For such complex problems geographical information system (GIS) can act as an effective tool to find an optimum solution. In real life, representation of environmental and economical criteria using crisp sets is not realistic. Decisions are generally taken considering overall picture. Representation of such complex phenomena can be achieved efficiently using fuzzy sets as demonstrated in our study.

GIS provides an extensive tool to conduct complex analysis of spatial information. Further, we feel requirement undertaking cost-benefit analysis for the solar photovoltaic power plant and transmission and distribution losses through a separate study for strategic planning. With inclusion of important socio-political criteria, GIS can provide good results that can help energy planners to draft the policies for development of programs such as solar parks and solar cities.

VI. Acknowledgement

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