INTEGRATING INFORMATION THEORY AND TOPSIS FOR MAPPING SOLAR POWER GENERATION POTENTIAL IN INDIAN STATES

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ABSTRACT

Energy production, renewable energy in particular, is under special radar across the globe and also in India. To encourage favourable FDI (foreign direct investment) flow in our country the government policies have been adequately modified; especially opening doors for private participation. The flip side to this investment attraction includes multiple challenges including the one of inadequate literature on the prospect or opportunity of renewable energy generation in different states in India. The paper tries to bridge such knowledge gap and is focused on mapping solar power generation potential in Indian states, a promising renewable energy sector. The purpose of mapping was to rank the Indian states and the same was done by using TOPSIS, the classical MCDM approach. This method was applied after integrating it with information theory whose key measure is entropy, Shannon's entropy to be precise. The relative importance of criterions was quantified from such entropic measures. Finally the TOPSIS rank derived was put to rank correlation test with the ranks of the relatively important criterions and two additional intuitive criterions of interest to understand the nature of relation between them.

KEYWORDS :
Solar Power Potential, MCDM, TOPSIS, Information Theory, Shannon's Weight.

INTRODUCTION

Energy production has always remained a matter of great importance and interest across the globe and India has been a major contributor to it. While the energy requirement in India has primarily been met from the conventional resources; fossil fuels to be precise that includes coal, petroleum, mineral based oils etc, the same generates huge pollutants in the atmosphere and carries the fear of such fossil fuels getting consumed at a much faster rate than their rate of generation. India is one of the top five energy consuming countries in the world, accounting for approximately 4% of the total global electricity generation and contributing 4.43 per cent to the global renewable generation capacity (CEA, International Renewable Energy Agency (IRENA), 2016). The conscious shift and focus towards alternative energy generation across the globe is also seen in India. In fact in 1982 the Indian Government set up the Department of Non-conventional Energy Sources, the first ministry of renewable energy in the world, which undertook a number of developmental programs and demonstration projects. India's energy policy is paying attention on safe and sound energy resources to meet up the demand of its growing economy (Kumar, et al., 2015)

In this regard, many renewable energy options have been tried in our country. The sources of most of the renewable energy options come either directly or indirectly from the sun. Sunlight, or solar energy, can be used directly for heating and lighting homes and other buildings, for generating electricity and a variety of commercial and industrial uses. The sun's heat also drives the winds, whose energy, is captured with wind turbines. Also, the winds and the sun's heat cause water to evaporate which turns into rain or snow and flows downhill into rivers or streams, and its energy can be captured using hydroelectric power. However, not all renewable energy resources come from the sun. Geothermal energy taps the Earth's internal heat for a variety of uses and the energy of the ocean's tides come from the gravitational pull of the moon and the sun upon the Earth.

According to IBEF (2017) report, the Indian renewable energy sector is the second most attractive renewable energy market in the world. It added record 11.0 GW in wind and solar power capacity in 2016-17. The focus of Government of India has shifted to clean energy after it ratified the Paris Agreement. With the increased support of government and improved economics, the sector has become attractive from investors perspective and India ranked second in Renewable Energy Attractive Index 2017. According to data released by the Department of Industrial Policy and Promotion (DIPP), FDI inflows in the Indian non-conventional energy sector between April 2000 and March 2017 stood at US$ 5.2 billion. Also, Foreign Direct Investment (FDI) up to 100% is permitted under the automatic route for renewable energy generation and distribution projects subject to provisions of The Electricity Act, 2003.

In such an industrial scenario, where there is huge government support coupled with rising demand for renewable power, India is at the perfect juncture of being considered as an investment destination in power sector. However, the researchers feel existence of a gap in view of reports or studies that may guide potential investors for location selection in India. The potential of solar power generation in Indian states is unexplored and it is felt that evaluation of the same may be best determined under multiple criterions. The chosen variables or criterions selected from existing literature include number of household depends on solid fuel lighting, number of un-electrified villages (UE), demand of power or power deficit, space availability which is proportional to the area of waste land and inversely proportional with the population density and solar radiation power potential. Multi-criteria decision making (MCDM) methods are most suitable for analysis of such problems. Of the different MCDM methods available; viz. SAW (Simple Additive Weighting), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), AHP (Analytical Hierarchy Process), VIKOR (Vise Kriterijumska Optimizacija I Kompromisno Resenje) etc, the TOPSIS approach has been used to identify the solar energy or power potential in Indian states, owing to its intuitive nature and criterion weights evaluated from Information Thoery i.e. entropic considerations.

LITERATURE REVIEW

Literature review was conducted on solar energy generation in India, Government policies and measures taken, factors affecting solar power generation and topics related to renewable energy generation. Both individual and institutional researches were consulted to have an apt understanding and theoretical base on the subject; identify the areas where researches has been done and explore areas where research is needed i.e. frame the research gap. **(*Kapoor et al., 2014*)** in their research paper "*Evolution of solar energy in India: A review*" have tried to outline the journey of solar energy in India since 1950 till date and highlighted the potential issues as barriers and challenges for better planning and management in the field of solar energy. **(*Khare, Vikas et al., 2013*)** presents in a coherent and integrated way the major constraints hampering the development of renewable energy in India through their work "*Status of solar wind renewable energy in India*". They have shown that condition of renewable energy sources such as solar and wind system is satisfactory in India but requires further attention on specific technological systems and better policy management. An overview of technical, economic and policy aspects of solar energy development and the status of solar energy in terms of resource potential, existing capacity, along with historical trends and future growth prospects of solar energy have been analyzed in the research paper "*Solar Energy Fundamentals and Challenges in Indian restructured power sector*" ***(Upadhyay & Chowdhury, 2014*)**. The paper also highlights that ways of improving the efficiency of renewable power generation lay in technology up gradation. The paper "*The Renewable Energy Sector in India: an overview of research and activity*" (***Mezzetti, 2011***) gives an overview of the present scenario and the projected growth in the next decade and tried to highlight some of the priorities identified in India for R&D and technology transfer. (***Akkas et al., 2017***) suggested in their research paper "*Optimal Site Selection for a Solar Power Plant in the Central Anatolian Region of Turkey*" about location selection in the regions of Turkey, which is key to PVPS's establishment. They had analyzed, the criteria for selecting the appropriate location by the multi-criteria decision making (MCDM) methods and concluded by finding the city that is most suitable for installation of solar power plants. The study on "*A Decision Support System for Selection of Solar Power Plant Locations by Applying Fuzzy AHP and TOPSIS: An Empirical Study*" (***Kengpol et al., 2013***) also provides an approach about the site selection. The research proposes a decision support system for avoiding flood on solar power plant site selection in Thailand and integrates the qualitative and quantitative variables based on adoption of the Fuzzy Analytic Hierarchy Process (Fuzzy AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) model. The research work, "*Optimal site selection for sitting a solar park using multi-criteria decision analysis and geographical information systems*" describes a general integrated framework to evaluate land suitability for the optimal placement of photovoltaic solar power plants, which is based on a combination of a geographic information system (GIS), remote sensing techniques, and multi-criteria decision-making methods ***(Georgiou & Skarlatos, 2016*)**. The study on *"Land Suitability Analysis for Solar Farms Exploitation Using GIS and Fuzzy Analytic Hierarchy Process (FAHP)—A Case Study of Iran"* (***Noorollahi et al., 2016***) had developed a two-step framework which provides an overview about the best solar energy enabled regions of Iran considering the geographical location and climatic conditions of Iran. In the first step, the map of unsuitable regions is extracted based on the defined constraints. In the next step, in order to identify the suitability of different regions, 11 defined criteria, including solar radiation, average annual temperatures, distance from power transmission lines, distance from major roads, distance from residential area, elevation, slope, land use, average annual cloudy days, average annual humidity and average annual dusty days, are identified. The relative weights of defined criteria and sub-criteria are also determined applying fuzzy analytical hierarchy process (FAHP) technique. Usability of MCDM techniques and approaches in sustainable and renewable energy planning problems was highlighted in the research work "*A survey of Multi-Criteria Decision Making Technique used in Renewable Energy Planning*" (***Shimraya et al., 2017***). It confirms that MCDM techniques can assist stakeholders and decision makers in unraveling some of the uncertainties inherent in renewable energy decision making. The generation process of electricity through solar thermal energy in Indian perspective is highlighted in "*Scope and Application of Solar Thermal Energy in India-A Review*" (***Dwivedi et al., 2013***). "*Growth of Solar Energy in India – Present Status and Future Possibilities*" (***Basu et al., 2015***) demonstrated how utilization of solar energy in India has got prime importance in the present scenario. It also reviewed the recent advances in developing the STE and SPV technologies for solar power generation. The study "*Solar energy in India: Strategies, policies, perspectives and future potential*" (***Sharma et al., 2012***) makes an effort to summarize the availability, current status, strategies, perspectives, promotion policies, major achievements and future potential of solar energy options in India. It was found that study on solar power generation potential in Indian states have not been conducted in a multi criteria environment and the same forms the basis of the present study. Specific objectives were framed based on the gap area.

OBJECTIVES

The present research work frames two basic objectives

1. Ranking 29 states of India in terms of solar power generation potential (excluding Telangana as it's a newly formed state).
2. Evaluate the relative importance level or weights of criterions influencing solar power generation potential.
3. Finding out the nature of relationships between the state ranks (as per solar power generation potential) and the state ranks of the 5 most important variables and 2 other intuitive variables.

RESEARCH FRAMEWORK

RESEARCH DESIGN

A systematic study design is resorted to address the research objectives. Descriptive study forms the basis of the ensuing study. The descriptive form of research allows one to draw rich inference that leads to important recommendations. Prioritizing Indian states with respect to solar energy generation potential is accomplished using TOPSIS, the classical MCDM approach while relative importance of criterions have been determined using Shannon's Entropy approach of Information Theory. The author used R 3.4.0 version programming language and software environment for all computations made in the present study.

METHODOLOGY

TOPSIS (Technique for order performance by similarity to ideal solution) is one of the known classical MCDM methods, and was first developed by Hwang and Yoon (1981). It is based upon the concept that the chosen alternative should have the shortest distance from the positive ideal solution and farthest distance from the negative ideal solution. The method introduces two reference points but does not consider the relative importance of the distances from these points. This method is not only very intuitive and practical but also an effective one. In this method, the performance and the weights of each criterion are given as exact (precise) values. A review of the TOPSIS approach is presented below. The best decision alternative may be evaluated using TOPSIS through a series of steps shown below:

Step 1: Normalization of Decision Matrix

$$n_{ij} = {x_{ij}} \Big/ {\sqrt{\sum_{j=1}^{m} x_{ij}^2}} \text{ ; j = 1,2,……m \& i = 1,2,……n}$$

Step 2: Weighted normalized decision matrix. The weighted normalized values are calculated as

$v_{ij} = w_i \, n_{ij}$, j = 1,2,……m; i = 1,2,……n &

w_i = weight of the i^th^ attribute or criterion and $\sum_{i=1}^{n} w_i = 1$

Evaluation of weight is dealt separately under the section 'Choice of Weights'.

Step 3: Determination of Positive and Negative Ideal solution

$$A^{+} = \{ v_1^{+}, \dots, v_n^{+} \} = \{ \left(\max_j v_{ij} \middle| i \in I \right), \left(\min_j v_{ij} \middle| i \in J \right) \}$$

$$A^{-} = \{ v_1^{-}, \dots, v_n^{-} \} = \{ \left(\min_j v_{ij} \middle| i \in I \right), \left(\max_j v_{ij} \middle| i \in J \right) \}$$

where I is associated with the benefit criteria, and J is associated with the loss criteria.

Step 4: Calculation of Separation Measures, using the n-dimensional Euclidean distance.

The separation of each alternative from the positive ideal solution is given by

$$d_j^{+} = \left\{ \sum_{i=1}^{n} \left(v_{ij} - v_i^{+} \right)^2 \right\}^{\frac{1}{2}}, \text{ j = 1,…m}$$

The separation of each alternative from the negative ideal solution is given by

$$d_j^- = \left\{ \sum_{i=1}^{n} \left(v_{ij} - v_i^- \right)^2 \right\}^{\frac{1}{2}}, \text{j = 1,…m}$$

Step 5: Calculation of Relative Closeness to Ideal Solution. The relative closeness of the alternative A_j with respect to A^+ is defined as

$$R_j = \frac{d_j^-}{\left(d_j^+ + d_j^-\right)}, \text{j = 1,…m}$$

Since $d_j^- \geq 0$ and $d_j^+ \geq 0$, then clearly, $R_j \in [0, 1]$

Step 6: Ranking the preference order. For ranking using relative closeness value, the greater the value better is the alternative. Thus, the alternatives may be ranked in decreasing order.

Choice of Weights

In typical MCDM environment, weights of attributes reflect the relative importance in decision making process. Because the evaluation of criteria entails diverse opinions and meanings, one cannot assume equal importance of criterion. There are two categories of weighting methods: subjective methods and objective methods. The subjective methods determine weight solely according to the preference or judgments of decision makers. Mathematical methods such as the eigenvector method, weighted least square method, and mathematical programming models are applied to calculate overall evaluation of each decision maker. The objective methods determines weights by solving mathematical models automatically without any consideration of the decision maker's preferences, for example, the entropy method, multiple objective programming, etc. Many objective weighting measures had been proposed by researchers. Shannon's entropy concept (Shannon & Weaver, 1947) is well suited for weight evaluation. The Shannon entropy is a measure of uncertainty in information formulated in terms of probability theory. Shannon developed this for a measure of information in a communication stream and is popularly known as Information Theory. Later research has applied his measure to a wide range of applications including spectral analysis (Burg, 1967), and even in social sciences. Shannon's entropy is a highly established and popular method of weight determination in a multi-criteria environment. The procedure of Shannon's Weight determination involves a series of sequential steps as described below.

Step i. Normalization of the data matrix as $\boldsymbol{p_{ij} = \frac{x_{ij}}{\sum_{j=1}^{m} x_{ij}}}$, j = 1, 2, ….., m & i = 1,2,…., n

Raw data normalizing is done to eliminate the anomalies of disparate units of measurement so as allow comparison on a similar platform.

Step ii. Entropy E_i is calculated as $\boldsymbol{E_i = -h_0 \sum_{j=1}^{m} p_{ij} \, . \ln p_{ij}}$

i.e. $\boldsymbol{E_i = -h_0 \sum_{j=1}^{m} \frac{x_{ij}}{\sum_{j=1}^{m} x_{ij}} \ln \frac{x_{ij}}{\sum_{j=1}^{m} x_{ij}}}$, i = 1,2, …,n and

$\boldsymbol{h_0}$ is the entropy constant and is defined as $\boldsymbol{h_0 = (\ln m)^{-1}}$

Step iii. Defining $\boldsymbol{d_i}$ as $\boldsymbol{d_i = 1 - E_i}$ and

Step iv. Defining Shannon's Entropy Weight $\boldsymbol{W_i}$ as $\boldsymbol{W_i = \frac{d_i}{\sum_{1=1}^{n} d_i}}$

DATA COLLECTION

Out of the two different types of data sources, the researchers chose secondary data for the present study. The same has been collected from different government reports and websites like REC, Report of ministry of Power, Census report etc owing to their reliability.

ANALYSIS & FINDINGS

1. Correlation Test

The nature of relationship between the chosen criterions or variables was studied first and the results (Fig 1) show that the correlation values are pretty low except for a case where it is found to be 0.55 which is also not very high. It is thus expected that multi collinearity; a situation in which two or more explanatory variables is highly related linearly, may not exist. If multicollinear exists, then one may interpret that the estimate of impact of an independent variable on the dependent variable tends is less precise as the collinear independent variables contain same information about the dependent variable. Multi collinearity was tested and VIF (variance inflation factor), a measure of existence of multicollinearity, were found to be < 10 for all the variables (Fig 2), thereby indicating absence of multicollinearity in the data set. Hence, all criterions selected were retained.

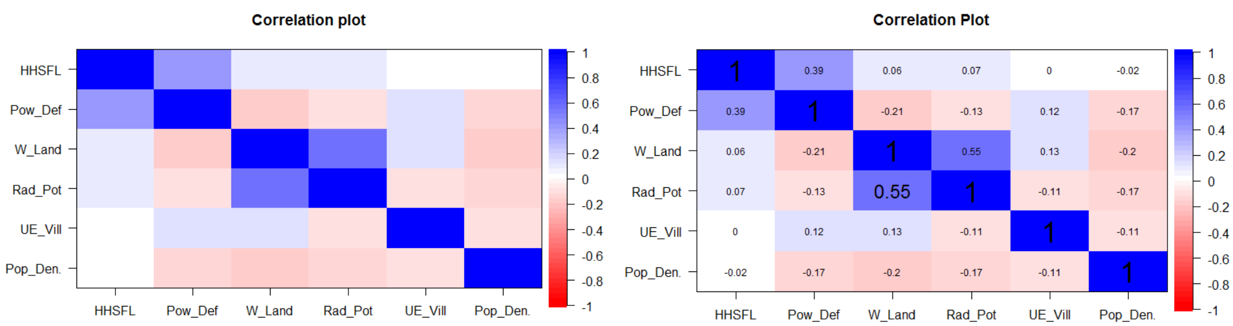


Fig 1: Correlation Plots (CorPlot); *Source* - R output

2. Multi-Collinearity Test

Variance Inflation factor					
HHSFL	Pow_Def	W_Land	Rad_Pot	UE_Vill	Pop_Den
1.227082	1.365607	1.621983	1.522234	1.102344	1.120709

Fig 2: VIF Table; *Source* - R output

3. Decision and Normalized Decision Matrix

	HHSFL	POW_DEF	W_LAND	RAD_POT	UE_VILL	POP_DEN
AP	650873	5939	2056	38.44	1	303
ARP	82147	74	1160	8.65	1191	17
ASM	3954090	2082	851	13.76	373	397
BIH	15720722	6656	432	11.20	214	1102
CHA	1338238	-1546	308	18.27	251	189
DEL	26724	-5774	16	2.05	1	11297
GOA	9362	1	1	0.88	1	394
GUJ	1157263	-4380	2595	35.77	1	308
HAR	438770	-1269	103	4.56	1	573
HP	45774	-295	656	33.84	1	123
J&K	280097	2438	288	111.05	101	57
JH	3307160	2796	1116	18.18	356	414
KAR	1212552	-3240	788	24.70	10	319
KER	416684	-1095	25	6.11	1	859
MP	5857437	-8853	1351	61.66	46	236
MAHA	3789062	-11333	1718	64.32	1	365
MAN	150624	37	24	10.63	62	122
MEGH	206169	150	421	5.86	121	132
MIZO	32056	-56	1	9.09	11	52
NAGA	72394	127	160	7.29	1	119
ORI	5468174	-659	1095	25.78	365	269
PUN	178520	3784	24	2.81	1	550
RAJ	4076342	170	2295	142.31	1	201
SIK	9354	-531	107	4.94	1	86
TN	1202045	-11649	492	17.67	1	555
TRI	250306	1073	1296	2.08	1	350
UP	20643515	7044	507	22.83	2	828
UT	235654	336	224	16.80	49	189
WB	8889813	7257	21	6.26	1	1029

Fig 3A: Decision Matrix; *Source* - Secondary Data

	[HHSFL]	[POW-DEF]	[W_LAND]	[RAD_POT]	[UE_VILL]	[POP_DEN]
[AP]	0.0219256616	4.055478e-01	0.3792403704	0.174922842	0.0007143202	0.026214240
[ARP]	0.0027672485	5.053129e-03	0.2139683024	0.039362190	0.8507553053	0.001470766
[ASM]	0.1331996244	1.421705e-01	0.1569715736	0.062615460	0.2664414180	0.034346711
[BIH]	0.5295767840	4.545085e-01	0.0796847471	0.050966072	0.1528645133	0.095340239
[CHA]	0.0450806125	6.828553e-05	0.0568122734	0.083138406	0.1792943590	0.016351457
[DEL]	0.0009002392	6.828553e-05	0.0029512869	0.009328611	0.0007143202	0.977367227
[GOA]	0.0003153734	6.828553e-05	0.0001844554	0.004004477	0.0007143202	0.034087164
[GUJ]	0.0389841903	6.828553e-05	0.4786618489	0.162772894	0.0007143202	0.026646818
[HAR]	0.0147806446	6.828553e-05	0.0189989096	0.020750472	0.0007143202	0.049573464
[HP]	0.0015419678	6.828553e-05	0.1210027641	0.153990347	0.0007143202	0.010641424
[J&K]	0.0094354997	1.664801e-01	0.0531231647	0.505337709	0.0721463357	0.004931392
[JH]	0.1114067889	1.909264e-01	0.2058522633	0.082728857	0.2542979754	0.035817476
[KAR]	0.0408466856	6.828553e-05	0.1453508813	0.112398392	0.0071432016	0.027598490
[KER]	0.0140366437	6.828553e-05	0.0046113858	0.027803813	0.0007143202	0.074316938
[MP]	0.1973168057	6.828553e-05	0.2491992901	0.280586431	0.0328587272	0.020417692
[MAHA]	0.1276404015	6.828553e-05	0.3168944341	0.292690873	0.0007143202	0.031578210
[MAN]	0.0050740019	2.526565e-03	0.0044269304	0.048372263	0.0442878496	0.010554909
[MEGH]	0.0069451210	1.024283e-02	0.0776557373	0.026666177	0.0864327388	0.011420065
[MIZO]	0.0010798558	6.828553e-05	0.0001844554	0.041364428	0.0078575217	0.004498813
[NAGA]	0.0024387036	8.672263e-03	0.0295128693	0.033173453	0.0007143202	0.010295362
[ORI]	0.1842038808	6.828553e-05	0.2019786992	0.117312977	0.2607268568	0.023272708
[PUN]	0.0060137217	2.583925e-01	0.0044269304	0.012787024	0.0007143202	0.047583604
[RAJ]	0.1373178717	1.160854e-02	0.4233252190	0.647587658	0.0007143202	0.017389644
[SIK]	0.0003151039	6.828553e-05	0.0197367313	0.022479678	0.0007143202	0.007440345
[TN]	0.0404927411	6.828553e-05	0.0907520731	0.080408080	0.0007143202	0.048016182
[TRI]	0.0084319439	6.828553e-05	0.2390542413	0.009465128	0.0007143202	0.030280475
[UP]	0.6954086640	4.810033e-01	0.0935189046	0.103888878	0.0014286403	0.071634953
[UT]	0.0079383687	2.294394e-02	0.0413180170	0.076449109	0.0350016876	0.016351457
[WB]	0.2994670715	4.955481e-01	0.0038735641	0.028486394	0.0007143202	0.089024597

Fig 3B: Normalized Decision Matrix; *Source* – R Output

Fig 3A represents the decision matrix formed by the original values of the alternatives against each criteria and 3B shows a matrix after statistic normalization was conducted on the original decision matrix. Statistical normalization was done to eliminate the effect of disparate units and transform the entire data set into a unit free data set. Fig 4 below shows the weights or relative importance of the six criterions. Relative importance of criterions has been evaluated using Shannon's entropy. It is found out that unelectrified villages have the highest importance in influencing solar power generation potential in Indian states. The two next important criterions are power deficiency and population density in order of decreasing importance.

4. Importance of Criterions (Shannon's Weight)

HHSFL	POW_DEF	W_LAND	RAD_POT	UE_VILL	POP_DEN
0.1696	0.2122	0.0906	0.0971	0.2242	0.2054

[HHSFL: Number of households that depend on solid fuel lighting, Pow_Def: Power Deficit, W_Land: Waste Land,
Rad_Pot: Solar Radiation Potential, UE_Vill: Unelectrified Villages, Pop_Den.: Population Density]

Fig 4: Shannon's Weight Table; *Source* - R output

5. Weighted Normalized Performance Table

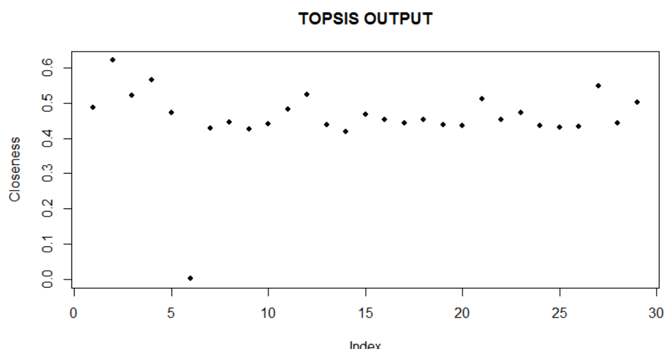
	[HHSFL]	[POW_DEF]	[W_LAND]	[RAD_POT]	[UE_VILL]	[POP_DEN]
[AP]	3.727302e-03	8.624759e-02	3.437783e-02	0.0169777486	0.000160161	0.0053846972
[ARP]	4.704245e-04	1.074646e-03	1.939605e-02	0.0038204351	0.190751752	0.0003021117
[ASM]	2.264357e-02	3.023531e-02	1.422934e-02	0.0060773627	0.059740053	0.0070551973
[BIH]	9.002658e-02	9.666003e-02	7.223357e-03	0.0049466905	0.034274454	0.0195839482
[CHA]	7.663579e-03	1.452224e-05	5.149986e-03	0.0080692889	0.040200411	0.0033587715
[DEL]	1.530382e-04	1.452224e-05	2.675317e-04	0.0009054210	0.000160161	0.2007621260
[GOA]	5.361260e-05	1.452224e-05	1.672073e-05	0.0003886685	0.000160161	0.0070018835
[GUJ]	6.627204e-03	1.452224e-05	4.339030e-02	0.0157984929	0.000160161	0.0054735536
[HAR]	2.512669e-03	1.452224e-05	1.722236e-03	0.0020140097	0.000160161	0.0101829422
[HP]	2.621302e-04	1.452224e-05	1.096880e-02	0.0149460721	0.000160161	0.0021858672
[J&K]	1.604009e-03	3.540522e-02	4.815571e-03	0.0490473201	0.016176261	0.0010129628
[JH]	1.893884e-02	4.060418e-02	1.866034e-02	0.0080295388	0.057017316	0.0073573090
[KAR]	6.943823e-03	1.452224e-05	1.317594e-02	0.0109092193	0.001601610	0.0056690376
[KER]	2.386190e-03	1.452224e-05	4.180183e-04	0.0026985964	0.000160161	0.0152655277
[MP]	3.354331e-02	1.452224e-05	2.258971e-02	0.0272332981	0.007367406	0.0041940216
[MAHA]	2.169851e-02	1.452224e-05	2.872622e-02	0.0284081371	0.000160161	0.0064865164
[MAN]	8.625662e-04	5.373229e-04	4.012976e-04	0.0046949393	0.009929982	0.0021680959
[MEGH]	1.180651e-03	2.178336e-03	7.039429e-03	0.0025881792	0.019379481	0.0023458087
[MIZO]	1.835725e-04	1.452224e-05	1.672073e-05	0.0040147694	0.001761771	0.0009241064
[NAGA]	4.145728e-04	1.844325e-03	2.675317e-03	0.0032197655	0.000160161	0.0021147821
[ORI]	3.131415e-02	1.452224e-05	1.830920e-02	0.0113862216	0.058458765	0.0047804737
[PUN]	1.022316e-03	5.495216e-02	4.012976e-04	0.0012410893	0.000160161	0.0097742028
[RAJ]	2.334366e-02	2.468781e-03	3.837408e-02	0.0628538867	0.000160161	0.0035720269
[SIK]	5.356679e-05	1.452224e-05	1.789119e-03	0.0021818439	0.000160161	0.0015283299
[TN]	6.883653e-03	1.452224e-05	8.226601e-03	0.0078042877	0.000160161	0.0098630592
[TRI]	1.433407e-03	1.452224e-05	2.167007e-02	0.0009186711	0.000160161	0.0062199473
[UP]	1.182175e-01	1.022947e-01	8.477412e-03	0.0100832987	0.000320322	0.0147146181
[UT]	1.349501e-03	4.879473e-03	3.745444e-03	0.0074200358	0.007847889	0.0033587715
[WB]	5.090857e-02	1.053879e-01	3.511354e-04	0.0027648467	0.000160161	0.0182866449

Fig 5: Normalized Performance Table; *Source* - R output

6. Ranking Indian States

Fig 6 represents Closeness value, its graphical representations and the TOPSIS Rank table. Closeness is a ratio, a measure of relative closeness and higher value of it suggests a better alternative and vice-versa. Thus, Arunachal Pradesh having the highest closeness value has emerged as the best alternative (1st rank) and Bihar having the second highest closeness value has rank 2 and so on. The TOPSIS rank output shows the order of states according to their potential of generating solar power. The graphical representations of the same give a visual depiction of the closeness. From this representation one can understand how distant or how close the states are from each other with respect to their solar power generation potential. For those states that are closer to each other in the spatial map, it may be considered that such states have similar solar power generation potential while those which are apart from each other are different in terms of their solar power generation potential. The rank output is shown in Fig 7 with the states at the top of the vertical (closeness) axis indicating the best alternative. It is found out that Delhi is way below the average potential and thus distant apart (at the bottom of Fig 7) from the other states.

State	Closeness Value
AP	0.487545552
ARP	0.620328489
ASM	0.521181785
BIH	0.565551605
CHA	0.473190318
DEL	0.001776903
GOA	0.427700905
GUJ	0.446115032
HAR	0.425280120
HP	0.439465253
J&K	0.481845058
JH	0.523711280
KAR	0.438601919
KER	0.418351427
MP	0.466636637
MAHA	0.452738125
MAN	0.442675699
MEGH	0.451627041
MIZ	0.437397413
NAG	0.435853636
ORI	0.511448877
PUN	0.451399201
RAJ	0.472252963
SIK	0.435313265
TN	0.430286454
TRI	0.433550061
UP	0.547362929
UT	0.442940570
WB	0.500936302



State	TOPSIS Rank
AP	8
ARP	1
ASM	5
BIH	2
CHA	10
DEL	29
GOA	26
GUJ	16
HAR	27
HP	19
J&K	9
JH	4
KAR	20
KER	28
MP	12
MAHA	13
MAN	18
MEGH	14
MIZ	21
NAG	22
ORI	6
PUN	15
RAJ	11
SIK	23
TN	25
TRI	24
UP	3
UT	17
WB	7

Fig 6: Closeness & TOPSIS Rank Output; *Source* - R output

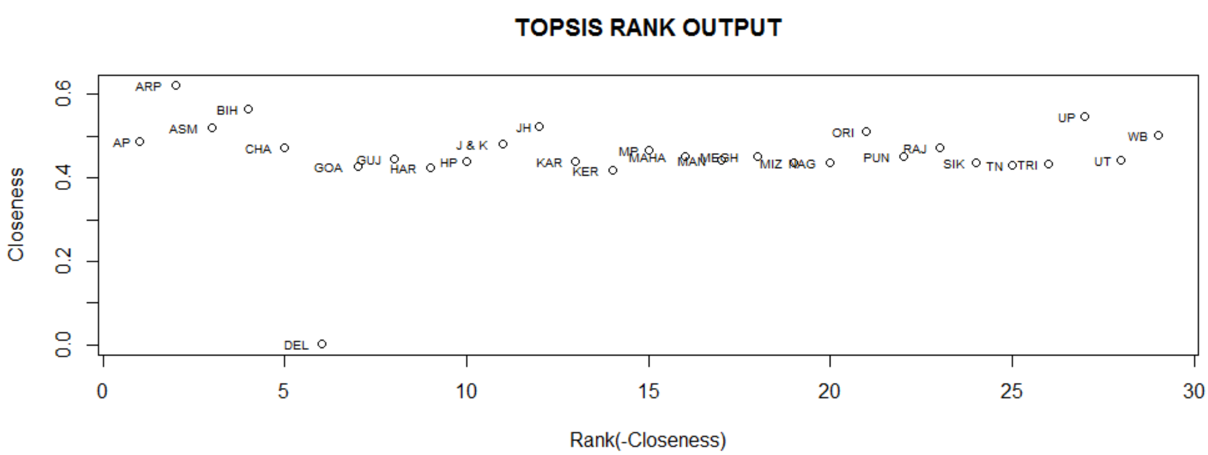


Fig 7: TOPSIS Rank Plot; *Source* - R output

7. Nature of Relationships (Rank Correlation)

The present study remains incomplete without ascertaining the association of the potential of solar energy generation in Indian states and the criteria considered in evaluating such potential. Here, the top 5 criterions have been considered according to their importance level (evaluated by Shannon's Entropic Weight determination method); namely un-electrified villages (UE_Vill), power deficiency (POW.DEF.), population density (POP.DEN), households using solid fuels (HHSF) and radiation potential (RAD.POT.). Furthermore, two more attributes beyond these 5 criteria have also been considered from an intuitive perspective; (1) the overall health of a state which is usually characterized by Average State Domestic Product Growth (AGSDP, calculated for the last three years) and (2) Governance & Political Stability (PS). Growth of SDP is also an indicator of the economic activities in a state and energy generation is a key component to such economic activities. Also, projects are planned, initiated but does not see the light of the day in many cases due to long and bureaucratic procedures of plan sanctions and political unrest in states. The researcher's vigil questions the existence of association between political stability in states and the solar energy generation potential. Since, the area of interest here is to know the association between two variables; correlation in particular i.e. whether the association is linear or not, adequate correlation tests need to be performed. Since the nature of association (linearity) is not exactly known, rank correlation tests have been performed. Spearman's Rank correlation coefficient (ρ), rho, a non-parametric test, is calculated by the formula $\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)}$, when there are no tied ranks and d_i is the difference in the ranks given to two variable values for each item of data. Here, the hypotheses are written as: Null Hypothesis : H_0 = There is no association (correlation) between the variables and Alternate Hypothesis : H_1 = There is association (correlation) between the variables

The following hypotheses have been framed to test the association, correlation in particular between solar power generation potential in Indian states (TOPSIS_Rank) and the 7 variables.

A1. TOPSIS_Rank & UE_Vill_Rank

A1 H_0: There is no association between TOPSIS_Rank and un-electrified villages in Indian states
A1 H_1: There is association between TOPSIS_Rank and un-electrified villages in Indian states

A2. TOPSIS_Rank & POW.DEF._Rank

A2 H_0: There is no association between TOPSIS_Rank and power deficiency in Indian states
A2 H_1: There is association between TOPSIS_Rank and power deficiency in Indian states

A3. TOPSIS_Rank & POP.DEN_Rank

A3 H_0: There is no association between TOPSIS_Rank and population density in Indian states
A3 H_1: There is association between TOPSIS_Rank and population density in Indian states

A4. TOPSIS_Rank & HHSF Rank

A4 H_0: There is no association between TOPSIS_Rank and households on solid fuel in Indian states
A4 H_1: There is association between TOPSIS_Rank and households on solid fuel in Indian states

A5. TOPSIS_Rank & RAD.POT._Rank

A5 H_0: There is no association between TOPSIS_Rank and radiation potential in Indian states
A5 H_1: There is association between TOPSIS_Rank and radiation potential in Indian states

A6. TOPSIS_Rank & PS_Rank

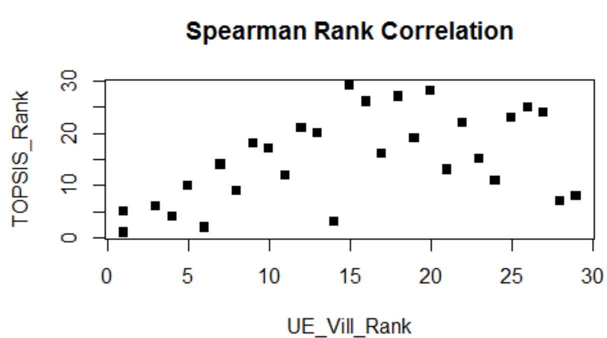
A6 H_0: There is no association between TOPSIS_Rank and political stability in Indian states
A6 H_1: There is association between TOPSIS_Rank and political stability in Indian states

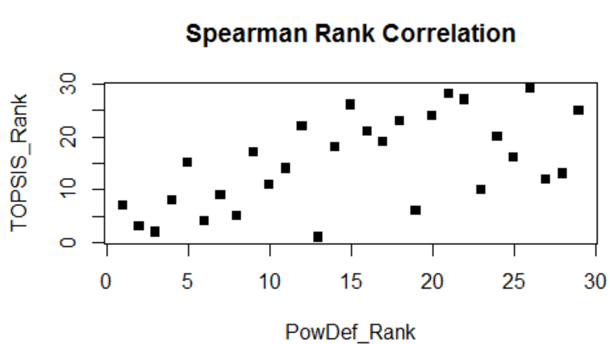
A7. TOPSIS_Rank & AGSDP_Gth_Rank

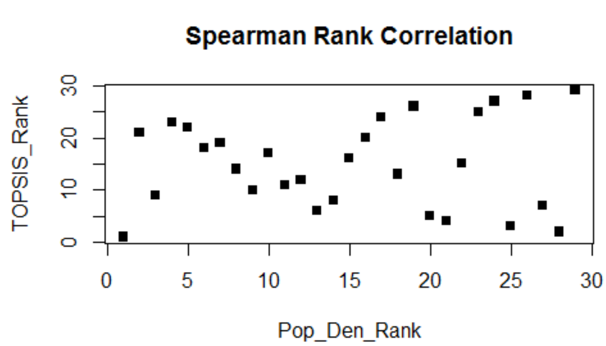
A7 H_0: There is no association between TOPSIS_Rank and avg. GSDP growth in Indian states
A7 H_1: There is association between TOPSIS_Rank and avg. GSDP growth in Indian states

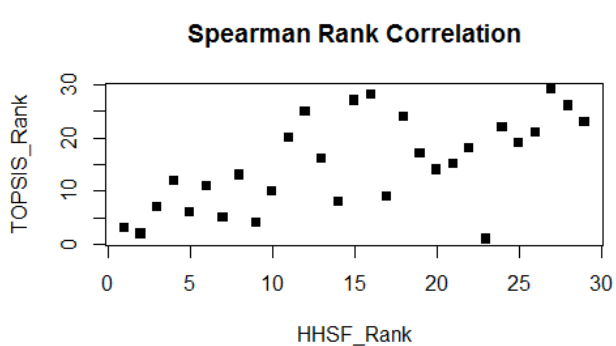
Rank Correlation Test Results

A1. Spearman's rank correlation rho between TOPSIS_Rank and UE_Vill_Rank is found to be 0.475428 with p-value = 0.009147. Thus, H_0 is rejected and alternative hypothesis H_1 accepted i.e. there is an association between solar energy generation potential and un-electrified villages in Indian states. **A2.** Spearman's rank correlation rho between TOPSIS_Rank and PowDef_Rank is found to be 0.5862069 with p-value = 0.001032. Thus, H_0 is rejected and alternative hypothesis H_1 accepted i.e. there is an association between solar energy generation potential and power deficiency in Indian states. **A3.** Spearman's rank correlation rho between TOPSIS_Rank and Pop_Den_Rank is found to be 0.06748768 with p-value = 0.7272. Thus, H_0 is accepted and alternative hypothesis H_1 rejected i.e. no association have been found to exist between solar energy generation potential and population density in Indian states. **A4.** Spearman's rank correlation rho between TOPSIS_Rank and HHSF_Rank is found to be 0.6226601 with p-value = 0.0004117. Thus, H_0 is rejected and alternative hypothesis H_1 accepted i.e. there is an association between solar energy generation potential and households on solid fuels in Indian states. **A5.** Spearman's rank correlation rho between TOPSIS_Rank and Rad_Pot_Rank is found to be 0.4950739 with p-value = 0.006932. Thus, H_0 is rejected and alternative hypothesis H_1 accepted i.e. there is an association between solar energy generation potential and radiation potential in Indian states. **A6.** Spearman's rank correlation rho between TOPSIS_Rank and PS_Rank is found to be -0.58867 with p-value = 0.000973. Thus, H_0 is rejected and alternative hypothesis H_1 accepted i.e. there is an association between solar energy generation potential and political stability in Indian states. The negative co-efficient value indicates that due to political instability or with increasing political instability, not much of the work has happened and hence there is a scope or potential of solar energy generation. **A7.** Spearman's rank correlation rho between TOPSIS_Rank and AGSDP_Gth_Rank is found to be -0.2950739 with p-value = 0.1202. Thus, Thus, H_0 is accepted and alternative hypothesis H_1 rejected i.e. there is no association between solar energy generation potential and average state domestic growth in Indian states.









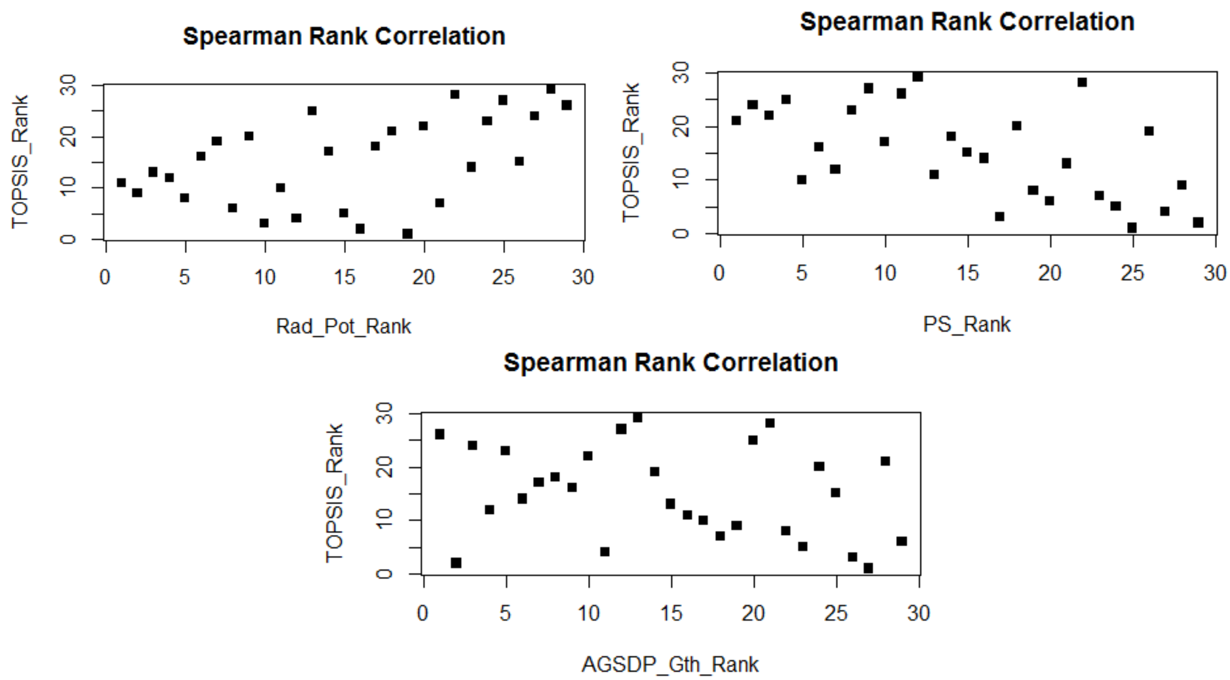


Table 10: Rank Correlation Plots; *Source* - R output

CONCLUSION

Past researches have shown that there is an enormous potential for solar power to grow in India. The present study attempts to find out the states where such potential is highest or the order of solar power generation potential in Indian states. From the present study it may be concluded that Arunachal Pradesh has the highest solar power generation potential followed by Bihar, Uttar Pradesh, Jharkhand and Assam in decreasing order of solar power generation potential. One finds that four of the top five states are from East India. Also, it is found out that size of state is not so important for solar power generation potential as eight of the ten states in the list of top ten states have smaller geographies. The findings of the ensuing study are expected to serve as a comprehensive report for organizations looking at investing in solar power generation in India.

RECOMMENDATIONS AND SCOPE OF FUTURE STUDY

The present study is not free from limitations as most other studies. To further make the study more robust one may include variables beyond the six that have been considered here. Furthermore, owing to non-availability of data of the same time period, the present study includes data of varying time frames as per the latest published data by government authorities. One may use some other ranking and weight determination method to get further perspective on the subject. The suggestions are indicative only and researchers may use their wisdom for further enhancement of the studied topic.

BIBLIOGRAPHY

- Akkas, O. P., Erten, M. Y., Cam, E., & Inanc, N. (2017). Optimal Site Selection for a Solar Power Plant in the Central Anatolian Region of Turkey. International Journal of Photoenergy Volume 2017, 13 pages.
- Basu, S. N., Karmakar, A., & Bhattacharya, P. (2015). Growth of Solar Energy in India – Present Status and Future Possibilities. International Journal of Electrical, Electronics and Computer Systems (IJEECS), 2347-2820.
- Bhattacharya, S., & Jana, C. (2009). Renewable energy in India: Historical developments and prospects. Energy , 981-991.
- Buragohain, T. (2012). Impact of Solar Energy in Rural Development in India. International Journal of Environmental Science and Development, Vol. 3.
- Buragohain, T. (2012). Impact of Solar Energy in Rural Development in India. International Journal of Environmental Science and Development.
- Burg, A. (1967). Light Sensitivity as Related to Age and Sex. Perceptual Motor Skills, 24, 1275-1288.
- Chang, H. J., & Hsieh, C. M. (2014). A TOPSIS Model For Chain Store Location Selection. Review of Integrative Business & Economics, 4 (1), 410-416.
- Chen, L. Y., & Huang, P. C. (2013). The strategic selecting criteria and performance by using the multiple criteria method. Systemics, Cybernetics and Informatics, 6 (1), 40-45.
- Dhingra, R., Jain, A., Pandey, A., & Mahajan, S. (2014). Assessment of Renewable Energy in India. International Journal of Environmental Science and Development.
- Dwivedi, A., Bari, A., & Dwivedi, G. (2013). Scope and Application of Solar Thermal Energy in India-A Review. International Journal of Engineering Research and Technology, 315-322.
- E A I Catalyzing Cleantech and Sustainability. (n.d.). Retrieved 2017, from www.eai.in: http://www.eai.in/ref/ae/sol/cs/sup/if/key_factors_to_consider_while_setting_up_a_solar_plant.html
- Elsayed, D. E., Dawood, D. A., & Karthikeyan, D. R. (2017). Evaluating Alternatives through the Application of Topsis Method with Entropy Weight. International Journal of Engineering Trends and Technology, 46 (2), 60-66.
- Erbiyik, H., Ozcan, S., & Karaboga, K. (2012). Retail store location selection problem with multiple analytical hierarchy process of decision making an application in Turkey. Procedia - Social and Behavioral Sciences, 58, 1405 – 1414.
- Garg, H., Agarwal, N., & Choubey, A. (2015). Entropy Based Multi-criteria Decision Making Method under Fuzzy Environment and Unknown Attribute Weights. Global Journal of Technology & Optimization, 6 (3), 1-4.
- Georgiou, A., & Skarlatos, D. (2016). Optimal site selection for sitting a solar park using multi-criteria decision analysis and geographical information systems. Geosci. Instrum. Method. Data Syst., 321-332.
- Gupta, R., Sachdeva, A., & Bhardwaj, A. (2010). Selection of 3pl Service Provider using Integrated Fuzzy Delphi and Fuzzy TOPSIS. Proceedings of the World Congress on Engineering and Computer Science, 2, 1-6.
- Gurung, S., & Phipon, R. (2016). Multi-criteria decision making for supplier selection using AHP and TOPSIS method. International Journal of Engineering Inventions, 6 (2), 13-17.
- Kabir, G., & Hasin, M. A. (2012). Framework for benchmarking online retailing performance using fuzzy AHP and TOPSIS method. International Journal of Industrial Engineering Computations, 3, 561–576.
- Kapoor, K., Pandey, K. K., Jain, A., & Nandan, A. (2014). Evolution of solar energy in India: A review. Renewable and Sustainable Energy Reviews 40, 475-487.

- Kengpol, A., Rontlaong, P., & Tuominen, M. (2013). A Decision Support System for Selection of Solar Power Plant Locations by Applying Fuzzy AHP and TOPSIS: An Empirical Study. Journal of Software Engineering and Applications, 470-481.
- Kumar, V., Kumar, R., & Maithani, A. (2015). Energy Policy in India. IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), 67-72.
- Mezzetti, S. (2011). The Renewable Energy Sector in India: an overview of research and activity. Indo-Italian Business Conference 2011. Chennai: European Business and Technology Centre.
- Noorollahi, E., Fadai, D., Shiraz, M. A., & Ghodsipour, S. H. (2016). Land Suitability Analysis for Solar Farms Exploitation Using GIS and Fuzzy Analytic Hierarchy. Energies 2016,9,643 , 1-24.
- Ojha, P. (., Gaur, G. K., Kumar, D. S., & Singh, D. L. (2014). Solar Energy and Economic Development In India: A Review. International Journal of Emerging Technology and Advanced Engineering.
- Osmani, A. R. (2014). Conventional Energy to Renewable Energy: Perspectives for India. The NEHU Journal, 41-60.
- Pangsri, P. (2015). Application of the Multi Criteria Decision Making Methods for Project Selection. Universal Journal of Management 3(1), 15-20.
- Paul, P., S, S. P., & Mohan, S. (2016). Selection of the most optimal contractor in Indian Construction Industry using Topsis and Extended Topsis model. IOSR Journal of Mechanical and Civil Engineering, 67-78.
- Pohekar, S., & Ramachandran, M. (2004). Application of multi-criteria decision making to sustainable energy planning—A review. Renewable and Sustainable Energy Reviews 8, 365-381.
- Ramachandraa, T., Jain, R., & das, G. K. (2011). Hotspots of solar potential in India. Renewable and Sustainable Energy Reviews, 3178-3186.
- Reddy, B. V., Sata, S. P., Reddy, S. K., & Babu, B. J. (2016). Solar Energy Analytics Using Internet of Things. International Journal of Applied Engineering Research, 4803-4806.
- Rural Electrification Corporation. (2017). Retrieved 2017, from http://www.recindia.nic.in: http://www.recindia.nic.in
- S, R., & KG, V. (2016). Solar Power – Current Status, Challenges and Policies in India. Journal of Engineering and Technology.
- S, S., Reddy, S., & S, V. (2014). A New Car Selection in the Market using TOPSIS Technique. International Journal of Engineering Research and General Science, 2 (4), 177-181.
- Sasikumar, N., & Jayasubramaniam, D. (2013). Solar Energy System in India. IOSR Journal of Business and Management (IOSR-JBM), 61-68.
- Savita Lolla, S. B. (2015). Wind and Solar Enaergy Resources in India. Energy Procedia 76, 187-192.
- Shahroudi, K., & Tonekaboni, S. S. (2012). Application Of Topsis Method To Supplier Selection In Iran Auto Supply Chain. Journal of Global Strategic Management, 6 (2), 123-131.
- Sharma, N. K., Tiwari, P. K., & Sood, Y. R. (2012). Solar energy in India: Strategies, policies, perspectives and future potential. Renewable and Sustainable Energy Reviews, 933-941.
- Shimraya, B. A., Singhb, K. M., & Mehta, R. K. (2017). A survey of Multi-Criteria Decision Making Technique used in Renewable Energy Planning. International Journal of Computer (IJC), 124-140.
- Srivastava, S. P., & Srivastava, S. P. (2013). Solar energy and its future role in Indian economy. International Journal of Environmental Science: Development and Monitoring.
- Sun, C. C., & Lin, G. T. (2009). Using fuzzy TOPSIS method for evaluating the competitive advantages of shopping websites. Expert Systems with Applications, 36, 11764–11771.
- Upadhyay, A., & Chowdhury, A. (2014). Solar Energy Fundamentals and Challenges in Indian restructured power sector. International Journal of Scientific and Research Publications.

- Venkatakrishnan, & Rengaraj. (2014). OVERVIEW OF SOLAR ENERGY IN INDIA. International Journal of Development Research, 605-608.
- Vikas Khare, S. N. (2013). Renewable and Sustainable Energy Reviews. Elsevier, 1-10.
- Vikas Khare, S. N. (2013). Status of solar wind renewable energy in India. Renewable and Sustainable Energy Reviews 27, pp 1-10.
- Wang, P., Li, Y., Wang, Y. H., & Zhu, Z. Q. (2015). A New Method Based on TOPSIS and Response Surface Method for MCDM Problems with Interval Numbers. Mathematical Problems in Engineering, 1-12.
- WIKIPEDIA. (2011). Retrieved 2017, from https://en.wikipedia.org: https://en.wikipedia.org/wiki/List_of_states_and_union_territories_of_India_by_population
- Wikipedia. (n.d.). Retrieved 2017, from www.en.wikipedia.org: https://en.wikipedia.org/wiki/Electricity_sector_in_India
- www.currentresults.com. (1961-1990). Retrieved 2017, from Current results - Weather and science facts: https://www.currentresults.com/Weather/India/annual-sunshine.php
- Yadav, H. K., Kumar, V., & Yadav, V. K. (2015). Potential of Solar Energy in India: A Review. International Advanced Research Journal in Science, Engineering and Technology (IARJSET).