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Investigation of feasibility study of solar farms deployment using hybrid AHP-TOPSIS analysis: Case study of India

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ABSTRACT

Presently, the usage of solar energy has increased with the advent of Renewable Energy Sources (RES) and bypassing traditional energy sources such as fossil fuels. Government of India (GoI) is adopting various policy measures to promote diffusion of solar energy across the nation and has huge solar energy investment plans in near future. In this regard, selection of appropriate site for solar power installation is of prime concern. It is a critical issue that needs to be analyzed in depth for producing solar power efficiently because various key factors viz. social, technical, economic, environmental and political aspects are associated with it. Considering the fact that there are lots of factors which affect the solar farm site selection, it is imperative to organize them in a systematic hierarchy. In this direction, present study aims to select appropriate site in an Indian case using hybrid combination of two Multi Criteria Evaluation (MCE) methods- Analytical Hierarchical Process (AHP) and fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Present investigation reveals that Sonepat is the best location for solar installation followed by Rohtak, Chandigarh, Gurgaon and Hisar in state of Haryana, India. The purpose of the investigation is to present an effective, efficient and systematic decision support framework which might help policy planners in the evaluation process of appropriate solar farm site selection in India.

1. Introduction

Energy is the national resource and fundamental need of mankind [1]. Utilizing clean energy source is a major challenging issue for the mankind in 21st century [2]. World community is facing the challenges of climate change and global warming. Adoption of Renewable Energy (RE) systems is considered among most promising solutions to address presently existing issues worldwide. RE play a pivotal role in addressing climate changing issues and boost energy security [3]. Although the objective to achieve energy efficiency has been handled deliberately prolonged, very few nations have acted in serious manner and translated this into emphatic country policies [4]. India is among those few nations that have taken initiative to implement the necessary paradigm shift in the manner of producing, transmitting and distributing RE. The social and economic development of a country depends on electrical energy availability. In India, electricity demand has been increasing at continuous rate due to growing population, recent emerging industrial and agricultural sectors etc. [5]. The rapid growth of Indian economy has initiated the need to enhance existing energy capacity [6]. It is estimated that 20 GW of additional generation capacity per annum can only fulfill the growing needs [7].

In this direction, solar energy can play crucial role to increase energy independence and mitigate global warming aftereffects [8–10]. India is among few fortunate countries which have enormous potential of solar energy [11]. It receives solar radiation almost throughout the year because of its favorable geographical location [12–14]. India occupies seventh position in producing energy in the world and has plenty of both exhaustible as well as RES. Harnessing the untapped and unmatched solar potential would not only assist in improving total energy mixture but also reduce the emission of harmful and toxic gases. India has huge investment plans for solar power installation in near future such as 100 GW till 2022 in national solar mission [15–19]. To accomplish this target, it is necessary to identify the feasible locations for deployment of solar energy in the country. However, the present investigation focuses on Haryana state of India. The research motivation for present investigation is presented in subsequent subsection.

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1.1. Motivation of present study

Solar farm site selection is a vital strategic decision. It may puzzle the electricity generation, grid enterprises and concerned authorities due to amalgamation of economical perspective and sustainable development of the concerned region. Great efforts are underway regarding lowering the manufacturing costs and achieving higher efficiencies because solar energy technologies lack adequate maturity so far.

Moreover, the locations exhibiting sound solar potential need not be most suitable sites for establishing solar farms because there are lot of factors which affect this decision [20]. Therefore, solar farm site selection becomes one of the most indispensable concerns for administrators of solar industry for maximizing the overall performance [21]. Previous studies in this regard have focused on the factors influencing solar farms and assessed the positive or negative impacts. Literature review reveals that no study is available that ranks the influential factors of solar farm site selection.

Haryana state was formed on 1st November 1966. It is a major industrial hub that enjoys the 1st highest per capita income of the nation [22]. Within a couple of decades, it established itself as a prosperous entity. It shows growing agricultural sector as well as fast growing industrial and educational sector. Its economic strength is due to achievements in the fields of information technology, software exports, health sector, telecommunication, petro-chemical production and power generating capacity [23]. Haryana Power Generation Corporation Limited (HPGCL) has presently installed generation capacity of 2782.4 MW due to thermal power stations at Panipat, Hisar and Yamunanagar [24]. Haryana Government is planning to generate 200 MW power using solar energy, out of which 50 MW will be generated in 2015–16. Moreover, Haryana Renewable Energy Department (HAREDA) is also putting efforts to install 5 MW solar power plants sanctioned by Ministry of New and Renewable Energy (MNRE) in 2014-15. A feasibility analysis is being carried out to identify 2000 acres of land in Haryana state [25]. The present study is an effective step in this direction. In view of the above mentioned facts, certain objectives are set up which are presented in forthcoming subsection.

1.2. Objectives of present investigation

The present energy needs are being fulfilled using exhaustible and depleting fossil fuels which affects the environment in harmful manner [1]. Recognizing this serious concern, Haryana Government notified a “Policy for Promoting Generation of Electricity through RES” on November 23, 2005. Its prime objective is to provide favorable environment for solar energy establishments and its products. But for establishing solar farm, it is the need of hours to identify an accurate, systematic and efficient decision frame work which might assist the decision makers. Selecting unsuitable location for solar power plants may lead to wastage of energy and resources [5]. In this direction, the objectives of present study are as follows:

- To identify the key factors affecting the deployment of solar farm before its site selection.
- To organize and prioritize the recognized key factors to develop solar farm site selection decision framework.
- To select appropriate site for solar farming considering a real world example- Indian case.

Haryana state has been selected as a case example for present investigation because of its new peaks of growth and glory in industrialization, infrastructure and setting new benchmarks for the peers to achieve all-round progress [26]. Haryana state is segmented into four zones to select five promising locations and the best one is identified using AHP-fuzzy TOPSIS. Fuzzy decision-making is a powerful technique for decision making [27]. In the present research, AHP and the fuzzy TOPSIS have been identified as appropriate methodologies. AHP is a key multi attribute decision assisting method popular in both academic research and engineering applications. The unique features of AHP such as simple to understand and apply in complex issues spread it to multiple disciplines worldwide. TOPSIS is another technique that assists decision makers in multi-criteria real world issues such as organization of the complex problems to analyze, compare, and rank alternative solutions [28]. The present study is directed towards providing a support tool to the decision makers so that appropriate site may be selected to generate solar power efficiently.

The present investigation is organized as follows: Section 2 discusses related work regarding the solar farm site selection. Section 3 presents the recognized key factors through extensive literature review which might influence the selection of solar farms. Section 4 highlights the framework of present investigation. Section 5 elucidates the methodology utilized to carry out the investigation. A real world example has been presented in Section 6. In Section 7, results of AHP and fuzzy TOPSIS techniques have been discussed. Section 8 gives discussion of findings of the present investigation followed by concluding remarks with future suggestions.

2. Related work

This section explores the relevant literature on solar farm selection and discusses the research gaps to reach to the present investigation.

2.1. Solar energy farming and site selection

It is the prime concern to deploy sizable solar systems at suitable sites on national scale. Huge investment of land, money and manpower is required to install solar power plants. The identification of feasible geographical areas for implantation of solar projects is not only influenced by solar potential but other factors such as economic, environment, technological, society specific and risk aspect affect also the same [29]. Therefore, identification of the suitable geographical areas for developing solar plants is crucial [30].

The selection of well-suited site is among fundamental decisions in the starting-up, expanding, or relocating the units [21]. It is extremely important to identify and prioritize the feasible areas before construction of expensive solar farms so as to have the best productivity and moderate payback [29]. Specifying the priorities for solar projects would assist in lowering the socioeconomic cost, developing infrastructure, and preventing the environmental penalties. Moreover, such strategic decisions will affect the operation and maintenance of the system economically and help in developing the concerned regions in the most sustainable manner.

2.2. Importance of social, technical, economic, environmental and political factors

Recognition of social, technical, economic, environmental and political (STEEP) factors is the preliminary and vital phase for establishment of new solar farms and to avoid delays in approval procedures of central and state government [5]. An outline of the related work by various researchers is presented here. For example, Schlecht and Meyer has considered solar irradiation, site attributes, infrastructural connections, cost of development, market and political factors for pre-feasibility analysis and site selection for Concentrated Solar Power (CSP) [31]. Uyan has studied economic and environmental factors for study of selection of solar site in Karnipar district in Turkey [20]. Effat has considered various dimensions for solar site selection in Egypt country such as solar radiation mapping, aspect angle, proximity to power lines, main roads and cities [32]. Chen et al. has considered four dimensions in solar farms site selection that includes environment, orography, location and climatology [21]. Vafaeipour et al. has considered four criteria in selection of solar plant in Iran *i.e.* economical, environmental, social and risk. [29]. Khan et al. has taken various factors in solar site selection in Indian context which are availability of land and solar radiation, distance from national highways and transmission line, local climatic conditions, usage of nearby land, site topography, geotechnical and political issues [30]. Tahri et al. has considered climate, orography, location and land use as the most influential factors affecting the solar farm site selection in Sothern Morocco [33]. Lee et al. has listed various parameters for selection of site for solar farms such as solar resource assessments, availability of water and land, soil structure, geographical conditions and site topography [34]. Singh et al. has utilized availability of energy demand, solar radiation, land government policy, social acceptability and environmental issues for prioritization of Indian states [35].

In nutshell, social, technical, economic, environmental and political dimensions are important aspects for solar power plant development [36].

2.3. Research gaps

Ample academic literature regarding selection of suitable location for solar farm establishments is missing [5]. Moreover, it has been discovered that whatever literature is available on selection of solar farm site lies in context of various countries such as Turkey, Spain, New York, Iran, Sri Lanka, USA, Oman and Taiwan excluding India [20,29,36–42]. Studies pertaining to Indian context are very low and very few researchers have concentrated towards this strategic issue in India.

Choudhary and Shankar has presented a decision framework of Thermal Power Plants (TPPs) in Indian context but this study chooses central-western part of India [5]. Khan et al. has presented optimal site selection in Rajasthan state of India using Geographical Information Software (GIS) [30]. Moreover, study regarding the prioritization of Indian states by Singh et al. has not even considered the Haryana state which is rich in solar potential and planning for solar power installation in near future [35].

It is deduced from literature survey that studies concerning selection of appropriate solar site in northern India are missing in literature. Keeping in view the same, efforts has been made in the present investigation to utilize AHP-TOPSIS analysis for solar site selection in Haryana. Infact, to the best knowledge of the authors, the present investigation is the first attempt to use AHP-TOPSIS analysis for solar site selection in Haryana and are missing in Indian context.

To fulfill the research gap, initially, the important key factors were identified from the literature and validated in discussion with experts. Later, AHP-fuzzy TOPSIS was utilized to select most suitable location using finalized key factors.

3. Identification of key factors affecting the location of solar farms

Socio-political and historic framework conditions impart a major role in the deployment of new RE options [43] such as geographical locations, weather conditions, solar irradiation, and load consumption [44]. The various key factors that affect the location of solar farm site selection especially Photovoltaic (PV) technology has been categorized in STEEP aspects [45] presented as follows:

3.1. Social aspect (SA)

India has been failed to harness sound renewable potential for sustainable development so far because of neglecting the social aspect associated with it. One of the common problems is not involving the local communities that leads to widespread ownership issues, land tenure problems and unwillingness to pay for energy services [46]. Therefore, it is very crucial to consider and deal it in an appropriate manner [47].

3.1.1. Effect on agriculture, employment and tourism (SA1)

The selected PV site must act as a supplementary source of employment with agriculture and farming sector to workers [48]. Moreover, it must be ensured that the selected land should be barren [20]. The selected solar site must help in increasing the employment chances for deprived and exploited part of population such as women and poor young people suffering from long-duration unemployment [49]. It is expected from the mass that the induction of solar energy would reduce the unemployment and, with it, the social costs of unemployment [50].

3.1.2. Effect on economic progress of surrounding region (SA2)

Job creation is the byproduct of the socio-economic effects linked with the installation of RE and Energy Efficient (EE) technologies [51]. PV site selection adds to economic up gradation of the concerned region. It generates job and education opportunities by giving the provision of studying and working more hours in evening after sunset, enhancing social cohesion and women empowerment [52].

3.1.3. Public acceptance (SA3)

Local people may resist the PV farm because of lacking awareness regarding the advantages of solar energy and socio-environmental impacts of traditional energy sources [53]. Public perception and acceptance is the major component to the development of any energy technology [54]. Awareness of consumers regarding PV and its market acceptance is the most prominent challenge in promotion of solar energy, which is suffering from social bias [18]. Personal and psychological factors that affects local acceptance is considered among key factors in successful implementation of solar energy in the power sector [55].

3.1.4. Distance from residential area (SA4)

PV power plant must not be established near rural and urban residential areas because it may impact urban growth. A minimum distance of 500 m must be maintained from residential areas [20]. Moreover, it may support in capacity expansion in future as well [5]. Significant aspect for the successful development of RE production is the acceptance by the communities in the direct vicinity. In the academic and grey literature, local public resistance against infrastructure projects is known as the Not-In-My-Backyard (NIMBY) syndrome, which in turn is frequently used to refer to the broader term of community acceptance. NIMBY suggests that opposition/negative attitudes increase with decreasing distance of a residence to the location of the renewable power plant [56,57].

3.2. Technical aspect (TA)

Various scientific issues and uncertainties are linked with technical aspect of solar energy which require due consideration before PV site selection [58]. Haryana has offered tariff on the basis of technology used in PV such as for crystalline, thin film and rooftop it will charge INR 5.70, INR 5.36 and INR 5.32 respectively. It is fact that drafting such policies may ensure the quality of the solar plant but on the other side it may reduce the interest of developers to invest money for low tariffs [59]. Moreover, replacing corroded or failed components, especially in remote outer island locations, involve long lead times, sometimes many months, in some occasion even one year or more [46].

3.2.1. Solar radiation data availability (TA1)

It is very important to get accurate and readily available data if solar power plant is to be established. PV site must be selected after studying sufficient data such as Direct Normal Irradiance (DNI) and Global Horizontal Irradiance (GHI) of the selected site [15,16,58].

3.2.2. Skilled manpower availability (TA2)

Trained human resource having solar exposure, installers and technicians with adequate expertise is required to operate the PV power plants [60]. If the competent people are available in the area, it will be very helpful. Otherwise training may be provided to them but it adds to extra cost. At present, India has competent force to install only 2000 MW. Requirement of competent workforce for installing, maintaining and repairing activities is expected to grow in PV industry. It is estimated that over one million skilled workers will be needed by 2022 to meet the aim of national solar mission [18].

3.2.3. Climatic conditions (TA3)

The performance of PV system depends upon certain site-related factors viz. latitude, cloudy season and air pollution [61]. Moreover, it is known that solar energy is intermittent in nature [62]. Therefore, studying the climate of the site is very important to know the availability of sunshine over the year [63]. For example, Haryana contains 320 days of clear sun annually so it is a wise decision to establish a PV power plant in this region [1].

3.3. Economical aspect (EA)

The economical aspect of PV installation at a particular place depends on distance from roads, transmission lines and requirement of supporting infrastructure. Investment cost is generally higher in developing than in developed countries because of several reasons viz. incompetent labor force, bringing engineers from abroad, and underdeveloped infrastructure [64].

3.3.1. Infrastructural cost (EA1)

The generation place requires transmission facility, road facilities, water supply and other local infrastructure in order to transmit the power to the end user. [65]. Additional stand-by capacity of electricity generation is also required for the times when the intermittent RES cease to generate power [66].

3.3.2. Transmission grid accessibility (EA2)

Proximity to existing electrical transmission lines is important from economic point of view. Uyan has considered distance less than 3000 m as perfect site in Turkey [20].

3.3.3. Road and rail accessibility (EA3)

Distance from national highways and streamline roads can provide a good approximation of construction cost. Therefore, selected site must have optimum distance from road and rail facility.

3.4. Environmental aspect (EN)

The solar farm site selection must consider the environmental aspect which includes visual impact, impact on species, noise impact and harmful toxin emission.

3.4.1. Visual impact (EN1)

The visual impact of a solar farm is dependent on a combination of both the size and location of the plant [67]. Visual impacts primarily depend on the type of the scheme chosen and the surroundings *e.g.* if PV system is established near naturally beautiful area it will certainly enhance the visual aspect [68]. Local learning in the institutional context involves the creation of public acceptance concerning the visual impact of PV installations [69].

3.4.2. Wild life and endangered species impact (EN2)

Solar developments can also impact birds indirectly by destroying or degrading their large areas of habitat, displacing sensitive species, by causing disturbance (at both the construction and operational phases) that affects presence or breeding and/or foraging success of key species, and depleting or polluting ground water in efforts to keep PV panels clean [70].

3.4.3. Noise impact (EN3)

Solar energy is abundant, costless and pure which avoid creating noise or any kind of pollution to the environment [71]. The noise and disturbance generated by construction and maintenance activities in PV farms and chemical pollution generated to keep the PV panels clean can affect occupants of the particular area such as perches, nest sites, shade and lack of interest of novel species to the area [70].

3.4.4. Harmful toxin emission (EN4)

During manufacturing and gathering of PV panels, wafer is split in cells and many harmful chemicals are used. Moreover, there is always a risk of exposing of different solvents such as nitric acid, sodium hydroxide and hydrofluoric acid [72]. So, it is vital to consider how far the solar plant from urban area is.

3.5. Political aspect (PA)

This aspect involves the political commitment of the state government to establish a solar farm in a particular region. Political commitment from the government is indispensible for the success of a rural RE programs [73].

3.5.1. State government policies (PA1)

State government policies must be able to clearly state guidelines and installations plan. Specified framework for promoting solar technology may act as stimulator for solar farm selection site. Reliable institutional framework is significant in the achievement of a successful and long-lasting sustainable RE program [73].

3.5.2. Regulatory boundaries (PA2)

State government should have the synchronization and consistent alignment with central governments to frame stronger policies to stimulate the penetration of solar energy. Several agencies must be aligned consistently to motivate investors of solar energy. Moreover, a certain timeframe must be drafted over their investment [74]. The regulatory framework concerning clean technology projects holds up their progress due to not only unestablished policies and regulations, but also the need to replace the existing regulations [75].

3.5.3. Land acquisition (PA3)

Land use requirements is a significant aspect now-a-days as RE technologies may consume fertile land or affect biodiversity [76]. The maximum allowable land for renewable projects is under the jurisdiction of state governments [77]. Acquiring the land depends entirely on the policies of the state such as Gujarat and Rajasthan, states of India, has adopted investor friendly policies. For solar farm selection site, it is important that the land acquisition process must be time framed process which includes the agreement of the occupants in order to avoid unnecessary court cases and inquiries [78]. Moreover, it must be ensured that only degraded land to be used for PV development [62].

3.5.4. Resettlement and rehabilitation (PA4)

It is important to consider if land of farmers have been taken, proper compensation must be paid to them or equal area of land may be provided to them at some another region. In case of birds and animals, it must be ensured that their habitat must not be disturbed. Proper arrangement must be ensured in case of disturbances [5,79].

4. Research framework of present study

The layout of present investigation is based on the general procedure adopted to choose a suitable location for an industry. It starts with the selection of STEEP factors influencing the selection of

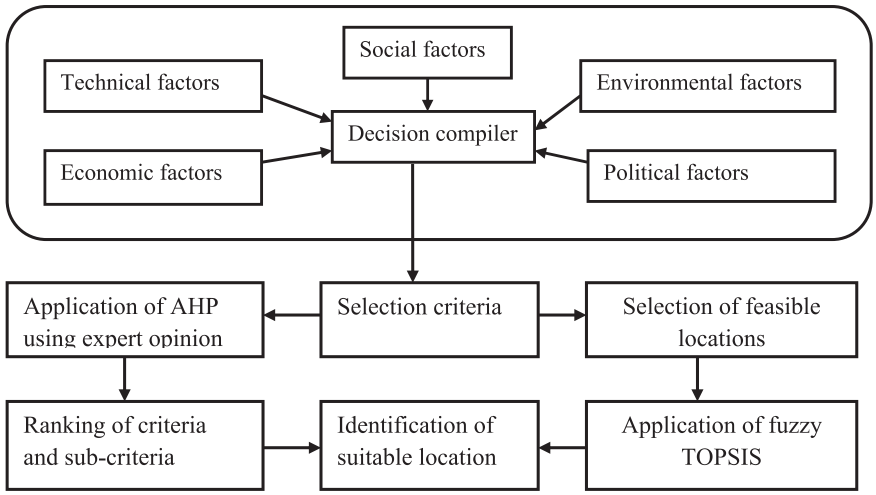

Fig. 1. Proposed framework of present study [Inspired from Singh et al. [35]].

solar farms in Indian context using extensive literature review approach and suggestions from experts'. It is followed by the construction of decision hierarchy of STEEP criteria and sub criteria using AHP technique. If any inconsistency arises in AHP results, experts are consulted again to address the irregularities. Afterwards, some feasible locations are considered on the basis of AHP results which are tested using fuzzy TOPSIS analysis and appropriate site is suggested. The proposed framework of present study is depicted in Fig. 1.

5. Methodology of present investigation

The methodology of this investigation involves the use of Multi-Attribute Decision Making (MADM) techniques presented as follows:

5.1. Multi-Criterion Decision Making (MCDM)- an outlook

MCDM methods assist in dealing with multiple often conflicting criteria in a structured way, allowing consideration of different preferences [54]. The selection of appropriate site for solar farm is a Multi-Criteria Evaluation (MCE) problem. MCE is a widely used concept developed in the 1960s that assists people in making the most suitable choice among many criteria [20]. There are lot of MCDM techniques available in literature which gained popularity for utilization in RE projects such as Analytical Hierarchy Process (AHP), Analytic Network Process (ANP), Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS), Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE), Multi-Attribute Utility Theory (MAUT), Multi-Objective Decision Making (MODM), Elimination and Choice Translating Reality (ELECTRE), VIKOR (VIsekriterijumsko KOmpromisno Rangiranje), and decision support systems [80]. An outline of all MCDM techniques has been discussed in [81]. All techniques have certain pros and cons which have been summarized in [5]. Table 1 depicts review of MCE techniques in site selection for RE. After review of literature, AHP is selected for present investigation as discussed in forthcoming sub-section.

5.1.1. Analytical Hierarchical Process (AHP)

AHP is a relative measurement technique for qualitative and intangible criterion proposed by Saaty [90]. It is a mathematical technique which is also known as decision analysis device. It is a MCDM tool which structures the complex issues in an hierarchical order, by simplifying evaluation of all criteria relevant in decision making [36,91]. AHP technique has been selected for the present investigation because of its several attractive features such as follows [5,15,20,36,90]:

- It assists in handling of complex, unstructured and multi-attribute issues.
- It facilitates the decision makers to analyze relevant problem to segment it into simpler and affordable sub-systems.
- It is equally applicable on quantitative as well as qualitative data.
- It uses hierarchical structure for presenting complicated decision issue.
- Its solution may be obtained using spreadsheet also.
- It gives us the provision of measuring consistency of the evaluating procedure.

A brief summary of AHP steps are as follows [20,33,92]:

Step 1: Firstly, set the goal which is followed by the selection of alternatives. Practical judgment is mandatory for selecting criteria which is a measurable facet assisting in illustration and enumeration of alternatives [30].

Step 2: Paired comparisons are needed in two segments such as follows:

(i) Among Criteria
(ii) Among Alternatives using each criterion.

Matrixes of pair-wise comparisons are created by the experts on the fundamental scale from 1 to 9. The comparison matrix is obtained as $(n \times n)$ where n denotes the number of criteria.

Step 3: Let X_{ij} denotes the order of preference of ith factor as compared to jth factor. Then $X_{ji} = \frac{1}{X_{ij}}$

Step 4: A normalized pair-wise comparison matrix is obtained by adopting the following procedure:

a. Calculate the sum of every column.
b. Divide every member of the matrix respectively by its obtained column sum.
c. Take average of the rows to obtain relative weights.

Step 5: Calculate Eigen vector, maximum Eigen value and Consistency Index (CI) using Eq. (1).

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{1}$$

Here, $\lambda_{\max}$ is Eigen value of paired comparison matrix and n is the no. of criteria.

Table 1
Review of recent work on site selection for RE installations (**Source**: Own elaboration).

Authors	Theories or Applications
Aydin [82]	Fuzzy set theory and Ordered weighted averaging (OWA) aggregator for site selection for wind and solar energy system for western Turkey.
Janke [40]	Multi-criteria GIS modeling for wind and solar farms in Colorado.
Nguyen and Pearce [83]	Multi criteria evaluation and AHP for estimating potential PV yield.
Talinli et al. [36]	Fuzzy AHP for wind farm site selection in Turkey.
Kang et al. [80]	Interpretive Structural Modeling (ISM), Benefit Opportunity Cost Risk (BOCR) analysis and fuzzy ANP for evaluating wind farm performance.
Charabi and Gastli [41]	AHP and OWA for PV site suitability in Oman.
Harren et al. (2011) [37]	Spatial Multi Criteria Analysis (SMCA) for wind farm site selection in New- York.
Choudhary and Shankar [5]	Fuzzy AHP and TOPSIS for TPPs site selection in India.
Vagiona and Karnikolas [84]	AHP for wind farm selection in Greece.
Gorsevski et al. [39]	Weighted linear Combination (WLC) technique for wind farm siting in North West Ohio.
Uyan [20]	AHP for solar farm site selection in Turkey.
Lozano et al. [85]	AHP and TOPSIS for evaluation of solar farm location in Spain.
Effat [32]	AHP for solar farm selection in Ismailia Governorate, Egypt.
Li [86]	AHP for selection of solar panel installation site in Canada.
Vafaeipour et al. [29]	Step-Wise Weight Assessment Ratio Analysis (SWARA) and Weighted Aggregates Sum Product Assessment (WASPAS) for prioritizing sites for solar projects in Iran.
Chen et al. [21]	DEcision-Making Trial and Evaluation Laboratory (DEMATEL) and DEMATEL-based ANP (DANP) for solar farm site selection
Tahri et al. [33]	AHP for evaluating solar farm locations in southern Morocco
Noorollahi et al. [87]	MCDM for wind farm site selection in Iran
Lozano et al. [88]	Use of AHP-TOPSIS-ELECTRE for PV optimum site selection in Spain
Lozano et al. [89]	Use of Fuzzy AHP and Fuzzy TOPSIS for wind farm site selection in Southeastern Spain

Step 6: Finally, Consistency Ratio (CR) is computed using Eq. (2).

$$CR = \frac{CI}{RI} \tag{2}$$

Where, RI stands for random index. The values of RI are depicted in Table 2.

The acceptable range of CR value is dependent on matrix order *e.g.* CR value for a 3×3 matrix is 0.05, for a 4×4 matrix it is 0.08 and 0.1 for all the matrices having order ≥5 [91,93].

5.1.2. Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS)

This technique was proposed by Hwang and Yoon [94]. The objective of this method is to provide the maximum and minimum gap from the negative and positive ideal solution respectively [95]. Although it is a famous method in MCDM but it suffers from several major shortcomings. In real analysis, it fails to cater ambiguous, uncertain and vague issues.

A better approach is to evaluate ratings and weights of the criteria using linguistic variables rather than numerical values. Decision makers are able to cater unquantifiable, incomplete, non-obtainable information and partially ignorant facts with the utilization of fuzzy sets theory. Thus, in the present study, fuzzy TOPSIS is utilized for ranking and evaluation of the problem [96].

The various steps involved in fuzzy TOPSIS approach are as follows [94]:

Step 1: Provide ratings to the linguistic variables according to criteria. The rating scale utilized is presented in Table 3. Further, matrix is constructed for alternatives in fuzzy form.

Step 2: Calculate the aggregate fuzzy weights for all criteria and obtain the aggregated fuzzy decision matrix. If the fuzzy rating of Nth decision maker is $X_{abN} = (l_{abN}, p_{abN}, u_{abN})$ Where, $a = 1, 2, 3........ m$; $b = 1, 2, 3, ... , n$ then fuzzy aggregated fuzzy ratings X_{ab} of solutions in accordance to each criteria is given by $X_{ab}(l_{ab}, p_{ab}, u_{ab})$ where,

Table 2
Possible values of RI [93].

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 3
Linguistic variable rating (Source: Prakash and Barua [94]).

Linguistic variables	Assigned Triangular Fuzzy Number (TFN)
Very Low (VL)	(1,2,3)
Low (L)	(2,3,4)
Medium (M)	(3,4,5)
High (H)	(4,5,6)
Very High (VH)	(5,6,7)
Excellent (E)	(6,7,8)

$$a = \min\{l_{abN}\}, \ b = \frac{1}{N}\sum_{N=1}^{N} p_{abN}, \ c = \max(u_{abN}) \tag{3}$$

Step 3: Normalize the aggregate fuzzy matrix by utilizing linear scale transformation. It is given by B where,

$$B = \left[p_{ij}\right]_{m\times n}$$

Here,$i = 1, 2, 3, ... , m$; $j = 1, 2, 3, ... , n$

$$p_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right); \ c_j^* = \max c_{ij} \text{ (Benefit criteria)} \tag{4}$$

$$p_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right); \ a_j^- = \min a_{ij} \text{ (Cost criteria)} \tag{5}$$

Step 4: Compute the weighted normalized decision matrix using Eq. (6).

$V = [v_{ij}]_{m\times n}$ Where, $i = 1, 2, 3, ... , m$; $j = 1, 2, 3, ... , n$

Here,

$$v_{ij} = p_{ij}(\times)w_j \tag{6}$$

Step 5: Identify fuzzy positive and negative ideal solutions using Eqs. (7) and (8) respectively.

$A^+ = \{v_1^+, ... , v_n^+\}$ Where,

$$v_j^+ = \{\max(v_{ij}) IFj \in J; \ \min v_{ij} IFj \in J'\}, j = 1, 2, 3, ... , n \tag{7}$$

$$A^- = \{v_1^-, \ldots, v_n^-\} \text{ Where } v_j^- = \{\max(v_{ij}) IFj \in J;\ \min v_{ij} IFj \in J'\}, j = 1, 2, 3, \ldots, n \tag{8}$$

Step 6: Compute the distance of each alternative from fuzzy positive and negative ideal solutions using Eq. (9).

$$d_i^+ = \left\{\sum_{j=1}^{n} (v_{ij} - v_{ij}^+)\right\}^{1/2};\ i = 1, 2, \ldots, m\ d_i^- = \left\{\sum_{j=1}^{n} (v_{ij} - v_{ij}^-)\right\}^{1/2};\ i = 1, 2, \ldots, m \tag{9}$$

Step 7: Compute the Closeness Coefficient (CC_i) and rank alternatives in descending order. It depicts the distance of each alternative from fuzzy negative and positive ideal solutions computed using Eq. (10).

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+};\ i = 1, 2, \ldots, n \tag{10}$$

Where, d_i^+ is distance from fuzzy positive ideal solution and d_i^- is distance from fuzzy negative ideal solution.

Step 8: Rank the alternatives in descending order in accordance with their respective CC_i. The best alternative is the one having maximum distance from fuzzy negative ideal solution and closest to the fuzzy positive ideal solution.

5.2. Sensitivity analysis

It is often considered that results provided by MCDM techniques lack preciseness. Therefore, it becomes indispensible to go one step further, *i.e.,* perform sensitivity analysis. It is "A method to determine the robustness of an assessment by examining the extent to which results are affected by changes in methods, models, values of unmeasured variables, or assumptions" [27].

In the present study, sensitivity analysis has been performed both on the results of AHP and fuzzy TOPSIS in order to validate the results.

5.3. An integrated AHP and Fuzzy TOPSIS methodology

Present investigation uses the hybrid combination of AHP and fuzzy-TOPSIS. An integrated AHP- fuzzy TOPSIS methodology is utilized to structure and prioritize the factors. Various researchers have utilized this hybrid combination. Table 4 depicts the usage of AHP-fuzzy TOPSIS in various fields by the eminent scholars.

The new concept in the approach lies in the fact that instead of using fuzzy environment during the determination of the weights; it has been introduced in achieving the final ranks of the candidate locations. It has been observed that it is easier and more precise to evaluate the level of influence of the criteria instead of characterizing its value. Therefore, linguistic values are utilized for evaluating the candidate locations, and more specifically the fuzzy TOPSIS method has been utilized for obtaining the final location [101].

Case analysis is performed to illustrate the utilization of the model for the problem. It demonstrates the effectiveness and feasibility of the suggested model [96]. A real world example is discussed in the succeeding section.

Table 4
AHP-fuzzy TOPSIS applications (Source: Own elaboration).

S. No	Applications utilizing AHP-Fuzzy TOPSIS	References
1.	A SWOT framework for analyzing the electricity supply chain.	[95]
2.	The integrated framework for analysis of electricity supply chain for Turkey.	[97]
3.	Project selection for oil-fields development.	[98]
4.	To rank Business to Consumer (B2C) e-commerce websites.	[96]
5.	For sustainable city logistics planning.	[99]
6.	Selection of project managers in construction firms.	[100]
7.	To access network selection in heterogeneous environment.	[101]
8.	The preference analysis for tourist choice of destination.	[102]
9.	Evaluation of high tech research project.	[103]
10.	An integrated agent-based recreational fishing simulation model.	[104]

6. A real world case example

Haryana lies between 27' 37" N to 3' 35" N latitude and 74' 28 E to 77' 36 E longitude, which spread over 44,200 km^2 (1.4% of the total geographical area of India). It occupies fourth position in terms of proportion of electrified households with 80.5%, after Himachal Pradesh (94.5%), Goa (92%) and Punjab (90.5%) in the country [9]. Haryana has total available generation capacity of around 2782.4 MW through its thermal plants. The State Government has proposed to add over 123 MW power generation capacity through solar plants during the 12th & 13th five year plan, which includes Yamunanagar, Hisar, Panipat and Faridabad [105].

Haryana has sound solar potential with 320 clear sunny days annually [1]. Fig. 2 depicts India's map that highlights Haryana state. In present study, Haryana has been divided into five zones *i.e.* northern, western, eastern, and southern and central zone. Five locations from these zones have been considered in the investigation such as Chandigarh from northern, Hisar from western, Sonepat from eastern, Gurgaon from southern region and Rohtak from central part as depicted in Fig. 3.

Locations have been chosen based on the criteria recognized and discussed in Section 3 using the experts' opinion.

6.1. Meteorological data of specific sites

The feasibility of solar energy system at any location depends on meteorological data on sunlight conditions for that region [107]. All meteorological data has been obtained from "National Aeronautics and Space Administration (NASA) Surface meteorology and Solar Energy (SSE) database- a RE resource website". The data was collected by the NASA Langley Research Center, Atmospheric Science Data Center, Surface Meteorological and Solar Energy (SSE) web portal supported by the NASA LaRC, Prediction of Worldwide Energy Resource (POWER) Project. [108]. This data is available globally with the same temporal, spatial resolution and data definition [109]. The most easily accessible database is given by NASA [110]. Data regarding insolation on horizontal and equator-pointed surface tilted at latitude angle, insolation clearness index, daylight hours, air temperature and relative humidity has been consulted. Table 5 illustrates the collected data of the specific locations.

GHI[1]: Averaged insolation on horizontal surface (MWh/m^2/year)
TI[2]: Annual averaged insolation on equator pointed surface *i.e.* tilted at latitude angle (KWh/m^2/day)
K[3]: Annual averaged insolation clearness index (dimensionless)
S[4]: Annual averaged daylight hours (h)
T[5]: Annual averaged air temperature (°C)
RH[6]: Annual averaged relative humidity (%)

Literature study reveals that the ideal value for Global Horizontal Insolation (GHI), Tilted Insolation (TI), Insolation clearness index (K), Daylight hours (S), air temperature (T) is greater than or equal to 1.8 MWh/m^2/Year, 5kWh/m^2/Day, 0.55, 12 h, 25 °C respectively and the value of Relative Humidity (RH) should lie between 44–52% [109]. All the selected locations are suitable from this perspective because each

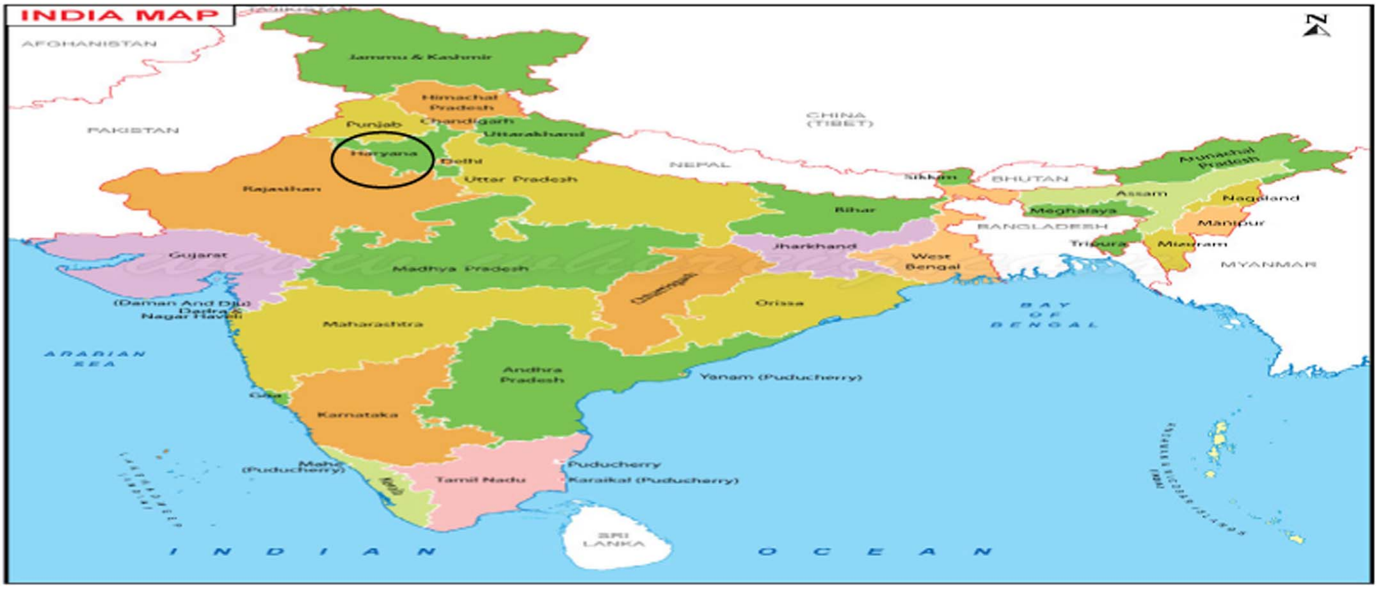

Fig. 2. Map of India (**Source**: www.wherebig.com [106]).

depicts the ideal values as illustrated in Table 6.

Therefore, utilizing the decision support framework proposed by the authors may help in reaching to the most suitable location as presented in succeeding section.

7. Data analysis and results

This section introduces the experts' information along with AHP and fuzzy TOPSIS analysis of STEEP criteria and their sub criteria to provide appropriate location in Haryana for deployment of solar farms.

7.1. Experts' information

While applying any MCDM method, it is crucial to employ qualified experts because reliability of the weights given from prejudiced experts is doubtful [29]. Most often managers, research specialists, stakeholders, or interest groups are employed for weight assignment to enhance decision power [40]. Assigning weights is the important part of any research activity because it provides relative importance of one criterion over the other. Most eligible and experienced experts were consulted to participate in two levels. Determination of criteria, alternatives under criteria and weights for AHP analysis was obtained in first step. Fuzzy TOPSIS analysis for site selection was made in subsequent step. Information regarding experts is illustrated in Table 7.

The selection criteria for the experts include individual industrial, commercial and consultancy experience (at least twelve years), decision making skills and expert knowledge in their domain etc. After finalizing expert panel, next task was to make pair wise comparisons. For this purpose, interactive discussion with multiple sessions was carried out with the experts.

7.2. Results of AHP

AHP framework of prioritizing STEEP factors influencing the solar farm site selection in Indian context may be organized in three segments:

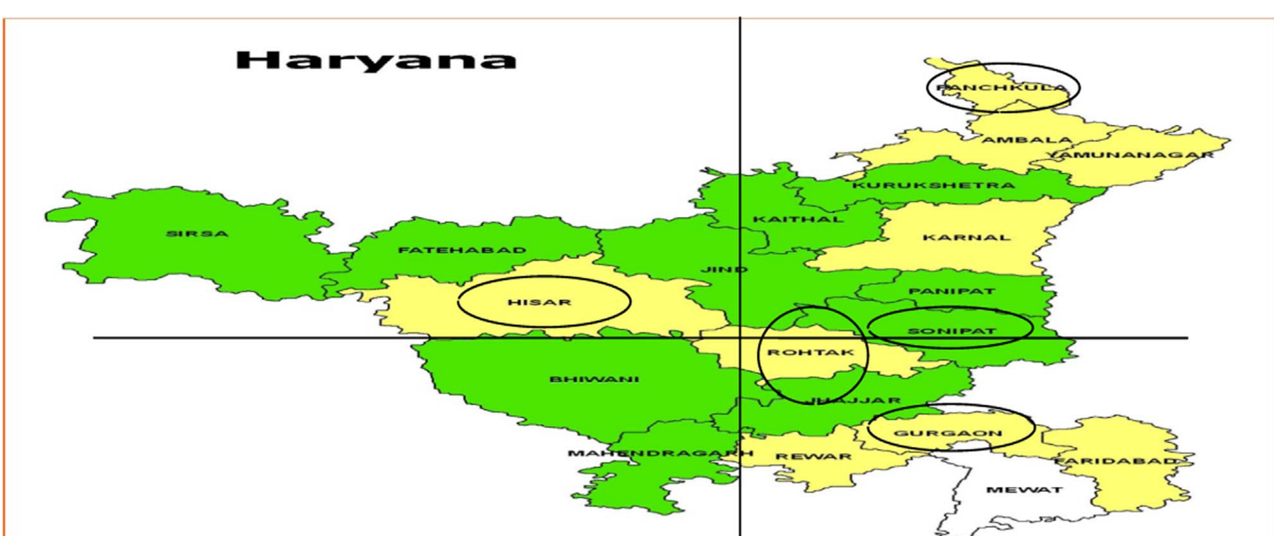

Fig. 3. Segmentation of Haryana in five zones (**Source**: www.janmsidh.com [61]).

Table 5
Average values of some meteorological parameters of specific sites in Haryana India.

Location	Longitude	Longitude	GHI[1]	TI[2]	K[3]	S[4]	T[5]	RH[6]
Gurgaon	28.27	77.01	1.85	5.48	0.57	12.13	23.8	52.2
Sonepat	28.99	77.02	1.84	5.51	0.57	12.12	23.8	52.2
Rohtak	28.89	76.58	1.83	5.42	0.56	12.12	23.6	51
Hisar	29.09	75.42	1.82	5.36	0.56	12.13	23.4	49.3
Chandigarh	30.75	76.78	1.98	6	0.62	12.14	20.9	51.3

Table 6
Judgment of meteorological parameters on desired scale.

Location	GHI[1] ≥1.8	TI[2] ≥5	K[3] ≥0.55	S[4] ≥12	T[5] ≤25	44≤ RH[6] ≤52
Gurgaon	√	√	√	√	√	√
Sonepat	√	√	√	√	√	√
Rohtak	√	√	√	√	√	√
Hisar	√	√	√	√	√	√
Chandigarh	√	√	√	√	√	√

Table 7
Experts' information (Modified from Vafaeipour et al. [29]).

Category	Classification	No. of experts
Working background	Senior level manager associated with solar industry	2
	Consultant dealing in green energy solutions	2
	Senior scientist from government agency	2
	Future studies expert	2
	Academicians	2
	Economic expert	2
Education level	Bachelor	0
	Master	6
	Ph.D.	6
Sex	Male	8
	Female	4

7.2.1. Segment 1: Constructing hierarchy of STEEP factors in solar farm site selection

Five criteria have been recognized that influences the solar farm site selection- Social aspect (SA), Technical aspect (TA), Economical aspect (EC), Environmental aspect (EN) and Political aspect (PA). In this segment, the rating of the criteria has been done as per the experts' suggestions to obtain a hierarchy as depicted in Table 8 along with the maximum Eigen values and CI.

'1.12' value of RI was utilized using Table 3 which finally led to '0.0640' value of CR (in acceptable limits). It is evident from Table 8 that political aspect is most influential criteria followed by economical, technical, environmental and social aspect.

Table 8
Ranking of criteria in solar farm selection in Indian context.

Criteria dimension category	SA	TA	EC	EN	PA	Global priority weighting	Rank
SA	1	0.5	0.5	0.33	0.5	0.0990	5th
TA	2	1	0.5	2	0.5	0.1844	3rd
EC	2	2	1	2	0.5	0.2422	2nd
EN	3	0.5	0.5	1	0.5	0.1562	4th
PA	2	2	2	2	1	0.3181	1st

Maximum Eigen value=5.28656, CI=0.0716398

7.2.2. Segment 2: constructing hierarchy of sub factors under main STEEP factors

Five STEEP factors consist of total eighteen sub-criteria. In this segment, AHP technique is applied on sub-criteria and thereafter, ranking and local priorities were obtained. The Tables depicting weights, ranking, maximum Eigen value and CI for every matrix has been detailed in Annexure-1.

7.2.3. Segment 3: constructing overall hierarchy of criteria and sub-criteria

Overall priority of STEEP factors and related sub factors was obtained by multiplying global weights of dimensions and local weights of the sub-criteria underlying them. After obtaining global weights of the factors, these are arranged in a hierarchy by providing everyone a specific rank according to the obtained value. The global priority weights of the criteria's along with their rankings are illustrated in Table 9.

7.2.4. Sensitivity analysis on AHP results

The core objective of sensitivity analysis is to evaluate the influencing degree of a variable on the overall model output by manipulating variables [111]. It is vital to be performed when there lies uncertainty in one or more parameters [112]. It helps in evaluation of minimum change in present weights of the criteria, that can alter the current positions of the alternatives [79]. This approach changes single variable at a time but may be extended to multiple variables [111]. It can be performed using EXCEL or software "Expert Choice" [112]. Tables illustrating the sensitivity analysis results have been provided in Annexure-2.

Application of sensitivity analysis reveals that AHP results are robust, significant and reliable. Fig. 4 shows the highest peak in political factor which is in-line with AHP results. Afterwards, the important task is to select most feasible location based on AHP results.

7.2.5. Results of fuzzy-TOPSIS analysis

In this subsection, data has been analyzed and validated using Fuzzy TOPSIS methodology and sensitivity analysis respectively. Expert group constructed fuzzy evaluation matrix into TFN using linguistic variables. This matrix has been developed after the comparison of locations against each sub-criterion provided in Table 10.

Considering the space constraints, single evaluation matrix by only one expert has been depicted. All the STEEP factors have been considered under cost criteria and therefore, goal minimization approach has been employed. The corresponding evaluation matrix in TFN is depicted in Table 11.

Further, aggregate fuzzy weights of the solutions, normalization of the aggregate fuzzy matrix and fuzzy weighted matrix have been obtained which are shown in Annexure-3. To compute fuzzy weighted matrix, criteria weights of AHP obtained in Table 9 has been employed. The present study has considered all STEEP factors under cost criteria and allocated the fuzzy positive and negative ideal solution as $v_1^+ = (0, 0, 0)$ and $v_1^- = (1, 1, 1)$ respectively thereafter each alternative distance is calculated using Eq. (7). In accordance with descending order of CC_i values, final ranking of the solutions has been obtained depicted in Table 12.

Table 9
Priority weights and rankings of STEEP factors in solar farm site selection in India.

Dimensions of barriers	Global weights of dimension	Ranks of dimensions	Sub-criteria	Local weight of sub-barriers	Global weights of barriers	Overall rankings of barriers
Social aspect (SA)	0.0990	5th	Effect on agriculture, employment and tourism (SA1)	0.1155	0.0114	18th
			Effect on economic progress of surrounding region (SA2)	0.1634	0.0161	17th
			Public acceptance (SA3)	0.2310	0.0229	15th
			Distance from residential area (SA4)	0.4901	0.0485	9th
Technical aspect (TA)	0.1844	3rd	Solar radiation data availability (TA1)	0.4934	0.0910	3rd
			Skilled manpower (TA2)	0.1958	0.0361	13th
			Climatic conditions (TA3)	0.3108	0.0573	7th
Economical aspect (EC)	0.2422	2nd	Infrastructural cost (EC1)	0.1634	0.03958	11th
			Transmission grid accessibility (EC2)	0.2970	0.0719	5th
			Road and rail accessibility (EC3)	0.5396	0.1307	2nd
Environmental aspect (EN)	0.1562	4th	Visual impact (EN1)	0.1205	0.0188	16th
			Wild life and endangered species impact (EN2)	0.4182	0.0653	6th
			Noise impact (EN3)	0.1906	0.0298	14th
			Harmful toxin emission (EN4)	0.2707	0.0423	10th
Political aspect (PA)	0.3181	1st	State government policies (PA1)	0.1689	0.0537	8th
			Regulatory boundaries (PA2)	0.1190	0.0379	12th
			Land acquisition (PA3)	0.4511	0.1435	1st
			Resettlement and rehabilitation (PA4)	0.2609	0.0830	4th

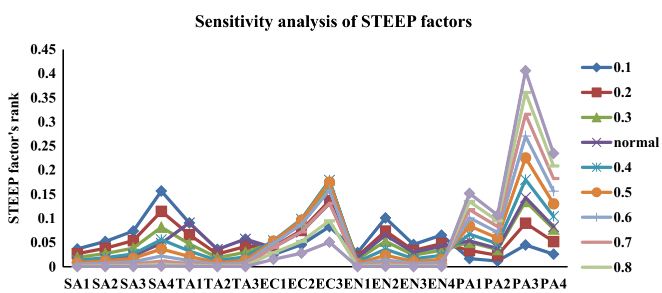

Fig. 4. Sensitivity analysis of STEEP factors influencing the solar site selection in India.

Table 10
Linguistics variables ratings matrix for alternatives (Expert 1).

Code	SA1	SA2	SA3	...	...	PA2	PA3	PA4
A1	H	M	H	..	..	H	L	M
A2	M	H	H	..	..	M	M	H
A3	H	VH	VH	..	..	M	M	L
A4	M	M	H	..	..	VH	M	M
A5	M	M	VH	..	..	VH	M	M

Table 11
TFN evaluation matrix for alternatives (Expert 1).

Code	SA1	SA2	SA3	...	...	PA2	PA3	PA4
A1	(4, 5, 6)	(3, 4, 5)	(4, 5, 6)	....	....	(4, 5, 6)	(2, 3, 4)	(3, 4, 5)
A2	(3, 4, 5)	(4, 5, 6)	(4, 5, 6)	....	....	(3, 4, 5)	(3, 4, 5)	(4, 5, 6)
A3	(4, 5, 6)	(5, 6, 7)	(5, 6, 7)	....	....	(3, 4, 5)	(3, 4, 5)	(2, 3, 4)
A4	(3, 4, 5)	(3, 4, 5)	(4, 5, 6)	....	....	(5, 6, 7)	(3, 4, 5)	(3, 4, 5)
A5	(3, 4, 5)	(3, 4, 5)	(5, 6, 7)	....	....	(5, 6, 7)	(3, 4, 5)	(3, 4, 5)

7.2.6. Sensitivity analysis on fuzzy-TOPSIS results

It is performed to analyze the effect of variation in the priority weights on the evaluation process and rankings [94]. Individual judgments of the decision makers have been utilized for obtaining weights of criteria so it is performed to analyze influence of weights of criteria on final ranking of candidate locations. It provides some idea about robustness of suggested framework. In order to validate the results, eighteen experiments were carried out depicted in Annexure-4. The result of the sensitivity analysis is shown in Fig. 5.

Table 12
Final ranking of the alternatives.

Code	Solar Plant	d_i^+	d_i^-	CC_i	Rank
A1	Gurgaon	0.3019	17.7208	0.9833	4
A2	Rohtak	0.2662	17.7513	0.9852	2
A3	Chandigarh	0.2888	17.7348	0.9840	3
A4	Hisar	0.3230	17.7068	0.9821	5
A5	Sonepat	0.2650	17.7506	0.9853	1

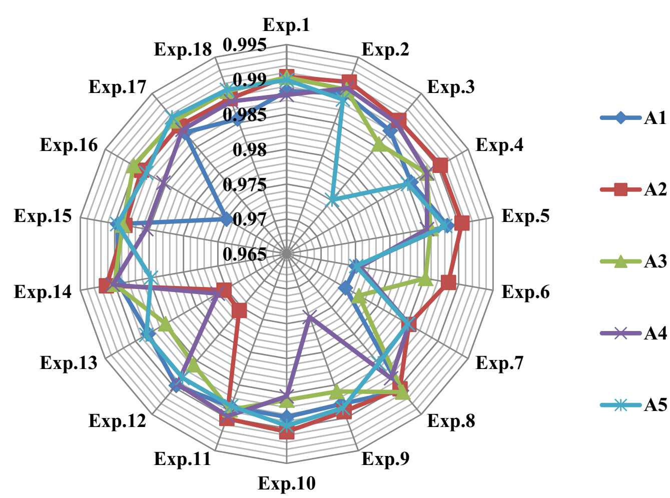

Fig. 5. Sensitivity analysis.

Fig. 5 shows that A2 has highest value in eleven experiments out of eighteen experiments (1–6, 7, 9–11, 14) while A1 depicts highest score in two experiments (12, 15), along with A3 in two experiments (8, 16), A4 in three experiments (7, 17, 18) and A5 in two experiments (13, 15).

It is obvious that the suggested framework is relatively sensitive to the criteria weights. Several other valuable findings evolved from the present investigation which is discussed in the forthcoming section.

8. Discussion of findings

Prior to present study, it was very hard to say which factors are more vital in solar farm site selection, but prioritizing them made it more logical and helpful for decision makers. Solar farm site selection is a valid problem in solar installation which has been solved with the help of MCDM techniques. Hybrid AHP and fuzzy TOPSIS methodology has been identified appropriate for carrying out the present investigation.

To make comparative evaluation of feasible locations for solar farm site selection in Haryana, extensive literature survey and experts' opinion have been utilized. The assessment process in real-life decision making situations is often not exact and contains fuzziness. This study presents a scientific research framework for comparative assessment of feasible locations with ability towards handling subjective, vague and imprecise data. The research findings have been enumerated and discussed as under:

Among STEEP factors, 'Political aspect' has been found to be the dominant factor and 'Social aspect' proved to be the lowest priority factor. Land acquisition (PA3) is found to attain first rank after AHP results. The top rankers are: PA3 > EC3 > TC1 > PA4 > EC2 and least rankers are: EN3 < SA3 < EN1 < SA2 < SA1.

To validate the adopted methodology, sensitivity analysis has been applied after application of AHP technique. Sensitivity analysis also indicates political aspect as the strongest factor.

Solar farm site location having highest CC_i value may be selected as most promising location for solar installation plant. Sonepat has been found most close to ideal solution whereas Hisar is most far; and Rohtak, Chandigarh, Gurgaon acquire second, third and fourth position respectively. This decision making will surely help decision makers for selecting appropriate location for solar installation.

To validate the adopted methodology, sensitivity analysis has also been applied after fuzzy TOPSIS technique. In this analysis, various experiments have been conducted by changing the criteria weights. Out of eighteen conducted experiments, A2 has been ranked 1st position in most of experiments. It may be inferred that selected fuzzy TOPSIS approach is quite robust and the decision making process has not been found highly influenced by slight variations in criteria weights.

Very less research work was found in literature for the solar farm selection site in context of India. The present investigation is unique in terms of choosing potential location for solar installation in one of the states in India. This work provides a systematic and efficient theoretical framework for recognition and prioritization of factors influencing solar farm selection sites. The study presents a decision support tool helpful in assisting authorities and decision makers for prioritization of the suitable sites in solar energy generation in Haryana.

Keeping in view the implication discussed in this section, it is obvious that present investigation is a robust contribution towards solar energy installations.

9. Wrapping Up

It is a well known fact that solar energy in India has unprecedented potential in sustainable development by providing several socioeconomic benefits that includes diversifying energy supply, enhancing regional and rural growth, creating domestic industries thereby increasing employment opportunities. Therefore, it is vital to identify suitable locations for its installation which is quite cumbersome. Surprisingly, very few studies are reported in literature on this critical issue in Indian context and especially, studies focusing at regional and the local levels are missing. Therefore, present investigation attempts to identify most suitable location in Haryana state which is rich in solar resources and feasibility studies for solar installation are in process. The authors of the present study with the best possible efforts have suggested suitable location to help officials, decision makers, developers and policy planners to set up solar farm.

This has been accomplished through the identification of key factors on the basis of literature review, and experts' opinions of decision making team. In this study, five key factors (STEEP factors) and eighteen sub factors have been identified. Using AHP methodology, these factors have been ranked on the basis of weights assigned by the experts comparing pair-wise. Application of sensitivity analysis has proved AHP results to be reliable and robust. Further, five feasible locations were recognized in Haryana for solar installation on the basis of identified STEEP factors and experts' inputs. With the help of NASA data, their feasibility is checked on the criteria of relative humidity, solar insolation, air temperature and day light hours. For choosing the most appropriate location among them, fuzzy TOPSIS methodology has been utilized in order to eliminate vagueness. Out of five locations, Sonepat is found to be the best location for solar implantation followed by Rohtak, Chandigarh, Gurgaon and Hisar. In order to validate the obtained results, sensitivity analysis on fuzzy TOPSIS results has also been carried out. This study has presented a suitable framework to evaluate best location for solar farm site selection in Haryana, India. The evaluation process of site selection is based on experts' involvement at each stage therefore; results are based on personal opinions, knowledge and judgment. However, to avoid this limitation, group of twelve experts' was utilized but other expert may provide different preferences. Other MCE techniques such as TOPSIS, ELECTRE, VIKOR, and ANP may be utilized to accomplish same objective and their results may be compared.

In summary, the present investigation serves as milestone to realize the target of government of India and state of Haryana for solar energy. It also plays a pivotal role to achieve the mission of GOI to realize the dream of make in India, digital India, and digital life and surely to achieve sustainable agriculture and digital life.

Acknowledgement

Authors would like to thank and appreciate the NASA RE resource website team for providing precious SSE data free of cost which can be accessed by the scholars to perform healthy research in effective and hassle free manner.

Annexure-1

9.1. Results of AHP

Segment 2: Constructing hierarchy of sub-criteria under STEEP criteria in solar farm site selection.
Ranking of dimension 1: Social sub-criteria in solar farm site selection.

Social aspect	IB1	IB2	IB3	IB4	Local priority weight	Rank
SA1	1	0.5	0.5	0.333333	0.1155	4th
SA2	2	1	0.5	0.3333	0.1634	3rd
SA3	2	2	1	0.3333	0.2310	2nd
SA4	3	3	3	1	0.4901	1st

Maximum Eigen value=4.12132; CI=0.0404401.

Ranking of dimension 2: Technical sub-criteria in solar farm site selection.

Technical aspect	TA1	TA2	TA3	Local priority weight	Rank
TA1	1	2	2	0.4934	1st
TA2	0.5	1	0.5	0.1958	3rd
TA3	0.5	2	1	0.3108	2nd

Maximum Eigen value=3.0536; CI=0.0268.

Ranking of dimension 3: Economical sub-criteria in solar farm site selection.

Economical aspect	EC1	EC2	EC3	Local priority weight	Rank
EC1	1	0.5	0.3333	0.1634	3rd
EC2	2	1	0.5	0.2970	2nd
EC3	3	2	1	0.5396	1st

Maximum Eigen value=3.0092; CI=0.0046.

Ranking of dimension 4: Environmental sub-criteria in solar farm site selection.

Environmental aspect	EN1	EN2	EN3	EN4	Local priority weight	Rank
EN1	1	0.3333	0.5	0.5	0.1205	4th
EN2	3	1	2	2	0.4182	1st
EN3	2	0.5	1	0.5	0.1906	3rd
EN4	2	0.5	2	1	0.2707	2nd

Maximum Eigen value=4.0710; CI=0.0237.

Ranking of dimension 5: Political sub-criteria in solar farm site selection.

Political aspect	PA1	PA2	PA3	PA4	Local priority weight	Rank
PA1	1	2	0.3333	0.5	0.1689	3rd
PA2	0.5	1	0.3333	0.5	0.1190	4th
PA3	3	3	1	2	0.4511	1st
PA4	2	2	0.5	1	0.2609	2nd

Maximum Eigen value=4.0710; CI=0.0237.

Annexure-2

Results of sensitivity analysis.

Dimensions' priority values after varying the values of "Political aspects" dimension .

Dimensions of factors	Global priority values after varying the values of “Political aspects” dimension									
	Normal	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
SA	**0.0990**	0.3201	0.2344	0.1673	0.1150	0.0751	0.0453	0.0241	0.0102	0.0024
TA	**0.1844**	0.1841	0.1348	0.0962	0.0661	0.0432	0.0261	0.0139	0.0059	0.0014
EC	**0.2422**	0.1540	0.2537	0.3102	0.3320	0.3251	0.2944	0.2437	0.1763	0.0943
EN	**0.1562**	0.2417	0.1770	0.1263	0.0869	0.0567	0.0342	0.0182	0.0077	0.0018
PA	**0.3181**	**0.1000**	**0.2000**	**0.3000**	**0.4000**	**0.5000**	**0.6000**	**0.7000**	**0.8000**	**0.9000**

Priority values of criteria after varying “Political aspects” dimension.

Criteria S. N.	Criteria's priority values in sensitivity analysis by changing “Political aspects” dimension values from 0.1 to 0.9									
	0.1	0.2	0.3	Normal (0.3181)	0.4	0.5	0.6	0.7	0.8	0.9
SA1	0.03697	0.02707	0.01932	0.0114	0.01328	0.00867	0.00523	0.00278	0.00118	0.00028
SA2	0.05230	0.03830	0.02734	0.0161	0.01879	0.01227	0.00740	0.00394	0.00167	0.00039
SA3	0.07394	0.05415	0.03865	0.0229	0.02657	0.01735	0.01046	0.00557	0.00236	0.00055
SA4	0.15688	0.11488	0.08199	0.0485	0.05636	0.03681	0.02220	0.01181	0.00500	0.00118
TA1	0.09083	0.06651	0.04747	0.0910	0.03261	0.02131	0.01288	0.00686	0.00291	0.00069
TA2	0.03605	0.02639	0.01884	0.0361	0.01294	0.00846	0.00511	0.00272	0.00116	0.00027
TA3	0.05722	0.04190	0.02990	0.0573	0.02054	0.01343	0.00811	0.00432	0.00183	0.00044
EC1	0.02516	0.04145	0.05069	0.03958	0.05425	0.05312	0.04810	0.03982	0.02881	0.01541
EC2	0.04574	0.07535	0.09213	0.0719	0.09860	0.09655	0.08744	0.07238	0.05236	0.02801
EC3	0.08310	0.13690	0.16738	0.1307	0.17915	0.17542	0.15886	0.13150	0.09513	0.05088
EN1	0.02912	0.02133	0.01522	0.0188	0.01047	0.00683	0.00412	0.00219	0.00093	0.00022
EN2	0.10108	0.07402	0.05282	0.0653	0.03634	0.02371	0.01430	0.00761	0.00322	0.00075
EN3	0.04607	0.03374	0.02407	0.0298	0.01656	0.01081	0.00652	0.00347	0.00147	0.00034
EN4	0.06543	0.04791	0.03419	0.0423	0.02352	0.01535	0.00926	0.00493	0.00208	0.00049
PA1	0.01689	0.03378	0.05067	0.0537	0.06756	0.08445	0.10134	0.11823	0.13512	0.15201
PA2	0.01190	0.02380	0.03570	0.0379	0.04760	0.05950	0.07140	0.08330	0.09520	0.10710
PA3	0.04511	0.09022	0.13533	0.1435	0.18044	0.22555	0.27066	0.31577	0.36088	0.40599
PA4	0.02609	0.05218	0.07827	0.0830	0.10436	0.13045	0.15654	0.18263	0.20872	0.23481

Annexure-3

Results of Fuzzy TOPSIS.
Aggregate fuzzy decision matrix for alternatives (utilizing Eq. (3)).

Code	SA1	SA2	SA3	...	...	PA2	PA3	PA4
A1	(3, 5.4, 7)	(4, 5.7, 7)	(3, 4.9, 6)	....	....	(1, 3.1, 5)	(3, 4.1, 6)	(2, 4.6, 6)
A2	(4, 6.1, 8)	(5, 6.9, 8)	(4, 5.1, 7)	....	....	(3, 5.5, 7)	(3, 5.3, 7)	(3, 4.9, 6)
A3	(4, 6.5, 8)	(4, 5.9, 7)	(2, 3.9, 5)	....	....	(4, 6.5, 8)	(4, 5.4, 7)	(4, 5.1, 7)
A4	(3, 4.5, 6)	(5, 6.1, 8)	(4, 5.9, 7)	....	....	(2, 4.4, 6)	(3, 5.3, 7)	(3, 5.5, 7)
A5	(4, 6.1, 8)	(3, 5.5, 7)	(1, 3.1, 5)	....	....	(3, 4.9, 6)	(5, 6.1, 8)	(4, 6.5, 8)

Normalized fuzzy decision matrix for alternatives (Using Eq. (3)).

Code	SA1	SA2	SA3	...	PA2	PA3	PA4
A1	(0.14, 0.18, 0.33)	(0.14, 0.18, 0.25)	(0.16, 0.24, 0.33)	....	(0.2, 0.62, 1)	(0.16, 0.24, 33)	(0.16, 0.21, 0.5)
A2	(0.12, 0.16, 0.25)	(0.12, 0.14, 0.2)	(0.14, 0.19, 0.25)	....	(0.14, 0.18, 0.33)	(0.14, 0.18, 0.33)	(0.16, 0.2, 0.33)
A3	(0.12, 0.15, 0.25)	(0.14, 0.16, 0.25)	(0.2, 0.25, 0.5)	....	(0.12, 0.15, 0.25)	(0.14, 0.18, 0.25)	(0.14, 0.19, 0.25)
A4	(0.16, 0.22, 0.33)	(0.12, 0.16, 0.2)	(0.14, 0.16, 0.25)	....	(0.16, 0.22, 0.5)	(0.14, 0.18, 0.33)	(0.14, 0.2, 0.33)
A5	(0.12, 0.16, 0.25)	(0.14, 0.18, 0.33)	(0.2, 0.62, 1)	....	(0.16, 0.2, 0.33)	(0.12, 0.16, 0.2)	(0.12, 0.15, 0.25)

Weighted normalized fuzzy decision matrix for alternatives (Using Eq. (4)).

Code	SA1	SA2	SA3	....	PA2	PA3	PA4
A1	(0.001, 0.002, 0.003)	(0.002, 0.003, 0.004)	(0.003, 0.005, 0.008)	....	(0.005, 0.006, 0.012)	(0.02, 0.035, 0.047)	(0.013, 0.018, 0.04)
A2	(0.001, 0.002, 0.03)	(0.002, 0.002, 0.003)	(0.003, 0.004, 0.006)	....	(0.004, 0.005, 0.012)	(0.02, 0.027, 0.047)	(0.013, 0.016, 0.027)
A3	(0.001, 0.002, 0.03)	(0.002, 0.003, 0.004)	(0.004, 0.006, 0.011)	....	(0.004, 0.006, 0.009)	(0.02, 0.026, 0.035)	(0.011, 0.01, 0.02)
A4	(0.002, 0.003, 0.04)	(0.002, 0.002, 0.003)	(0.003, 0.004, 0.005)	....	(0.006, 0.008, 0.018)	(0.02, 0.027, 0.047)	(0.011, 0.01, 0.02)
A5	(0.001, 0.002, 0.03)	(0.002, 0.003, 0.005)	(0.004, 0.014, 0.022)	....	(0.006, 0.007, 0.012)	(0.01, 0.023, 0.028)	(0.009, 0.011, 0.02)

Annexure-4

Results of sensitivity analysis of Fuzzy TOPSIS.
Sensitivity analysis.

Run	Experiments	A1	A2	A3	A4	A5
1	WSA1=0.55, WSA2-WPA4=0.015	0.9883	0.9904	0.9903	0.9878	0.9899
2	WSA2=0.55, WSA1; WSA3-WPA4=0.015	0.9895	0.9912	0.9900	0.9903	0.9885
3	WSA3= 0.55, WSA1-WSA2; WSA4-WPA4=0.015	0.9880	0.9900	0.9856	0.9895	0.9751
4	WSA4= 0.55, WSA1-WSA3; WTA1-WPA4=0.015	0.9856	0.9904	0.9881	0.9882	0.9850
5	WTA1= 0.55, WSA1-WSA4; WTA2-WPA4=0.015	0.9884	0.9905	0.9859	0.9854	0.9880
6	WTA2= 0.55, WSA1-WTA1, WTA3-WPA4=0.015	0.9751	0.9885	0.9852	0.9757	0.9751
7	WTA3= 0.55, WSA1-WTA2; WEC1-WPA4=0.015	0.9747	0.9852	0.9769	0.9852	0.9850
8	WEC1= 0.55, WSA1-WTA3; WEC2-WPA4=0.015	0.9906	0.9902	0.9908	0.9883	0.9854
9	WEC2= 0.55, WSA1-WEC1; WEC3-WPA4=0.015	0.9879	0.9890	0.9860	0.9746	0.9885
10	WEC3= 0.55, WSA1-WEC2; WEN1-WPA4=0.015	0.9884	0.9905	0.9859	0.9854	0.9896
11	WEC3= 0.55, WSA1-WEC2; WEN1-WPA4=0.015	0.9883	0.9901	0.9888	0.9897	0.9882
12	WEN1= 0.55, WSA1-WEC3; WEN2-WPA4=0.015	0.9896	0.9756	0.9857	0.9893	0.9882
13	WEN2= 0.55, WSA1-WEN1; WEN3-WPA4=0.015	0.9879	0.9754	0.9850	0.9764	0.9882
14	WEN3= 0.55, WSA1-WEN2; WEN4-WPA4=0.015	0.9895	0.9912	0.9900	0.9903	0.9847
15	WEN4= 0.55, WSA1-WEN3; WEN4-WPA4=0.015	0.9896	0.9885	0.9888	0.9854	0.9896
16	WPA1= 0.55, WSA1-WEN4; WPA2-WPA4=0.015	0.9749	0.9890	0.9903	0.9854	0.9882
17	WPA2= 0.55, WSA1-WPA14; WPA3-WPA4=0.015	0.9877	0.9890	0.9899	0.9882	0.9906
18	WSA1-WPA3=0.015, WPA4=0.55	0.9856	0.9887	0.9898	0.9883	0.9900

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