Performance Evaluation and Ranking of Sites of Solar Power Plants Through Grey Relation Methods in Fuzzy Environment

S V V Ramana[a*] and **M.L.S Devakumar**[b]

[a]Senior Lecturer in Mechanical Engineering, Government Polytechnic Vijayawada, India
[b]Professor of Mechanical Engineering, College of engineering, Javaharalal Nehru Technological University, Anantapur, India

Email: *svvramana369@gmail.com

Abstract
The purpose of this study is to develop a decision model for selecting solar farms. A MCDM model is proposed for the selection of a solar power plant site based on economic, technical, environmental, and sociopolitical criteria which contain 20 sub-criteria. For the purpose of determining the weights of the sub-criteria, the model utilizes the Relative Importance Index (RII) method. A four-stage procedure has been followed for this study, which involves the identification of criteria, the development of a questionnaire (survey), a confirmation factor analysis, the assessment of the degree of importance of criteria, and the ranking of alternative options using gray analysis in a fuzzy environment. An alternate site for a solar power plant is generated using Plackett-Burman Design and these alternatives are evaluated based on Grey Relation Analysis (GRA) and Grey Relation Projection (GRP) in a fuzzy environment.

1. Introduction

There are various types of renewable energy resources; however, photovoltaic (PV) solar energy is by far the most exploitable and provides more energy to the earth per hour than all the energy consumed by humans in a year (Lewis and D. G. Nocera, 2006). Furthermore, revenues created from PV solar markets are expected to exceed US$100 billion by 2020 (MOEA, 2008). Several efforts are being made to reduce the manufacturing costs and to improve the efficiency of PV solar energy systems (Parida *et al.*, 2011; Socorro *et al.*, 2012). The selection of the site for solar farms is one of the most important issues for administrators of the solar energy industry in order to ensure that solar farms perform as efficiently as possible.

A few previous studies have examined whether solar farms are located in areas with favorable or unfavorable climates (Bhaskar *et al.*, 2012; Hodson, 2014), in order to convey what factors impact solar farms and whether they have a positive or negative impact. The discoveries for developing a decision model for determining solar farm site selection have little contribution to that process. In addition, despite the interrelationships and influence weights among criteria being extremely useful for administrators to simultaneously consider interdependent variables within multiple criteria in the real world, there is a dearth of literature focused on these issues. As a result, this study aims to construct a decision model that can be used to evaluate and rank potential solar farm sites.

2. Literature Review

The selection of solar PV sites for utility-sized projects is an important decision because of the importance of weather factors, distance from residential areas and network connection, impact on local residential life, and environmental risks. The selection of a solar power plant site must be carefully considered as it represents an important decision.

Muhammet Deveci *et al.*, (2019) considered 44 factors in selecting the site for a solar power plant. This study examines twenty criteria under four main categories, namely: Economical, Technical, Environmental, and Socio-Political. We conducted this study in response to the lack of literature and in an attempt to determine the importance of the criteria affecting the site selection of solar power plant projects using Grey relation methods (GRA and GRP) decision making methods.

Using various methods of Multi-Criteria Decision Making (MCDM), Kim Ray *et al.,* (2020) defined how to find ideal locations for solar photovoltaics.

In a paper published by Muhammet Deveci *et al.*, (2021), the authors investigated the degree of importance of factors affecting the selection of solar photovoltaic (PV) sites through a novel logarithmic additive estimation of weight coefficients (LAAW) under a fuzzy environment.

The study conducted by Soydan *et al.,* (2021) sought to determine the most suitable location for solar energy plants and provide the option of building them at the most suitable locations. Using an analytical hierarchy process (AHP) method in GIS, eleven data layers were created (sunshine duration, solar radiation, slope, aspect, road, water sources, residential areas, earthquake fault lines, mine areas, power lines and transformers).

Daria Kereush andIgor Perovych (2017) proposed criteria for siting solar PV farms. A multicriteria decision analysis (MCDA) is proposed as a method of analyzing available technical information in order to support a decision making process.

In 2018, Aditya Sharma and Geeta Singh investigated and understood the optimal site selection and efficiency for photovoltaic systems in solar laboratories and explored the possibilities for their utilization.

With the aid of geographic information systems (GIS) and a multi-criteria decision-making (MCDM) technique, Al Garni, Hassan Z, and Awasthi, Anjali (2017) evaluated and selected the best location for utility-scale solar PV projects

The authors of Nabila Tabassum *et al.,* (2020) conducted a literature review to determine the criteria for selecting these farms based on Geographic Information System (GIS) and Analytical Hierarchy Process (AHP), taking into account factors such as solar radiation potential, site location, transportation, and technological-economic factors.

A decision and methodology were presented by Ghazanfar Khan and Shikha Rathi (2014) to locate potential sites for large-scale solar photovoltaic (SPV) plants based on various factors such as "analysis criteria" and "exclusion criteria".

Using Geographical Information Systems (GIS) technology, Ebru.H, Colak *et al.,* (2020) investigated the possibility of building a solar photovoltaic (PV) power plant in the Malatya Province of Turkey.

Using a fuzzy logic model, Yousefi *et al.,* (2018) selected a spatial site for solar power plants in the Markazi Province of Iran. The results of the research have been visualized and spatially analyzed using Geographic Information Systems (GIS).

Abdulaziz Alhammad *et al.,* (2022) developed a spatial MCDA framework for evaluation of sites for solar power plants with combination of GIS and Analytical Hierarchy Process (AHP) techniques to determine five sub-criteria weights (Slope, Global Horizontal Irradiance (GHI), proximity to roads, proximity to residential areas, and proximity to power lines).

Guaita-Pradas *et al.,* (2019) combined legal, political, and environmental criteria, including solar radiation intensity, local physical terrain, environment, and climate, as well as location criteria, such as distance from roads and power substations. Furthermore, GIS data (time series of solar radiation, digital elevation models (DEM), land cover, and temperature) are used as additional input parameters to identify areas for solar PV power generation.

A combined approach of Multi Criteria Analysis (MCA) and Geographic Information Systems (GIS) was presented by Khemiri *et al.,* (2018) for the optimal placement of solar photovoltaic large farms in Makkah region in western Saudi Arabia. As part of the multi-criteria analysis, a number of geographic criteria were taken into consideration, including solar radiation, topography, land use, accessibility, and proximity to electric transmission lines. The weight assigned to each criterion was determined by the Analytic Hierarchy Process (AHP) method.

3. MCDM Methods for Selection of Site for Solar Power Plant

Solar PV site selection has been the subject of numerous studies, which have considered a variety of main and sub-criteria. Moreover, there has been limited research on fuzzy MCDM models in the energy literature related to the selection of solar power plant sites. This study aims to evaluate the criteria used for selecting solar PV sites and to develop a decision support system based on grey relationship analysis and grey relation projection in a fuzzy environment.

Within the framework of this study, the economic sub-criteria namely, Initial investment cost (EC1), Operation and maintenance costs (EC2), Land cost (EC3), Construction and Infrastructure cost (EC4), Government Subsidies (EC5) and Payback Period (EC6).

In this study, the following technical sub-criteria namely, Distance to the network connection (TE1), Solar Radiation (TE2), Sunshine Hours (TE3) Temperature (TE4), Wind Speed (TE5), Rain Fall (TE6) are considered.
Besides analyzing the economical, technical aspects for site selection of solar power plants, it is equally important to analyze the social and political aspects as well. Public Acceptance (SP1), Skilled Manpower availability (SP2), Proximity to residential areas (SP3) and Population Density (SP4) are considered as socio-political sub-criteria.

Besides analyzing the technical, economical, and socio-political factors for evaluation of solar power plants, it is equally important to analyze environmental aspect well. Sub-criteria under environmental aspects namely: Life Cycle emissions (EV1), Distance to water resource areas (EV2), Polarized light Pollution (EV3) and Landscape Destruction (EV4) are examined within the scope of this study.

3.1Fuzzy *Grey Relation Analysis* (*FGRA*)

In this study, a fuzzy gray relational analysis (GRA) method is presented for determining where to locate a solar power plant. A triangular fuzzy number can be used to describe the weight of each criterion and the rating of all alternatives. Following is a description of the Methodology

Step-1: Obtain the fuzzy decision matrix.

The Plackett-Burman Design of Experiments is used to generate the alternatives and decision matrix. A linguistic variable is generated for each of the sub-criteria in order to evaluate them. Using the Fuzzy-GRA, the linguistic scale and corresponding triangular fuzzy numbers are calculated, as shown in Table1. A triangular fuzzy number is obtained by transforming linguistic data into triangular fuzzy numbers.

Table 1: Linguistic variable and triangular fuzzy number

S.No.	Value in the designs	Linguistic variable	Triangular fuzzy number
1	-1	Low (L)	(1,2,3)
2	0	Medium (M)	(2,3,4)
3	1	High (H)	(3,4,5)

Linguistic data is transformed into triangular fuzzy numbers.

Step-2: Normalize the decision matrix.

Normalization based on the characteristics ofthree types of criteria, namely larger-the-better (benefit), smaller-the-better (cost) or nominal-the-best (optimal), isused here to transform the various criteria scales intocomparable scales. Normalization formulae are presented below.

Let $\tilde{G}_{ij}$ be normalization of G_{ij}. $\tilde{G}_{ij}$ can be classified into following situations.

As G_{ij}belongs to cost criteria, $\tilde{G}_{ij} = \left(\frac{g_j^-}{g_{ijr}}, \frac{g_j^-}{g_{ijh}}, \frac{g_j^-}{g_{ijl}} \right)$, $g_j^- = \min_i\{g_{ijl}\}$, $\forall j$.

As G_{ij}belongs to cost criteria, $\tilde{G}_{ij} = \left(\frac{g_{ijr}}{g_j^+}, \frac{g_{ijh}}{g_j^+}, \frac{g_{ijl}}{g_j^+} \right)$, $g_j^+ = \max_i\{g_{ijr}\}$, $\forall j$.

Moreover, $\left[\tilde{G}_{i1}, \tilde{G}_{i2}, ..., \tilde{G}_{in}\right]$ is normalization of $[G_{i1}, G_{i2},\ldots,G_{in}]$.

Step-3: Obtain Relative weights of the sub-criteria.

Relative weights of the sub-criteria is obtained through relative importance method

Step-4: Obtain Weighted normalized decision matrix.

Using an appropriate normalization method, the various criteria scales are transformed into comparable scales based on three different types of criteria: large-the-better (benefit), small-the-better (cost), or nominally the best (optimal). The following formulae are provided for normalization.

$$\tilde{V} = \left[\tilde{v}_{ij}\right]_{m\times n} \quad \text{for i = 1, 2,…,m and j = 1,2,…,n}$$

where

$$\tilde{v}_{ij} = \tilde{r}_{ij} \times \tilde{w}_j$$

$$\tilde{v}_{ij} = \left(a_{ij}^*, b_{ij}^*, c_{ij}^*, d_{ij}^*\right)$$

Step-5: Obtain fuzzy positive and fuzzy negative ideal solutions.

Using fuzzy positive and fuzzy negative ideal solutions as reference sequences, fuzzy positive and fuzzy negative ideal solutions are determined. It can be defined for beneficial criteria as follows.

$$\tilde{A}^+ = \left(\max_j v_{ij}\right) = \left(\tilde{v}_1^+, \tilde{v}_2^+, ..., \tilde{v}_m^+\right), \qquad i = 1,2,\ldots,m.$$

$$\tilde{A}^- = \left(\max_j v_{ij}\right) = \left(\tilde{v}_1^-, \tilde{v}_2^-, ..., \tilde{v}_m^-\right), \qquad i = 1,2,\ldots,m.$$

where $v_i^+ = \left(a_i^+, b_i^+, c_i^+, d_i^+\right)$ and $v_i^- = \left(a_i^-, b_i^-, c_i^-, d_i^-\right)$, $i = 1,2,\ldots,m.$

Step-6: Obtain separation measures from positive and negative ideal solutions.

Based on the different separation measures of each alternative, the gray relational coefficient is calculated for each alternative from PIS and NIS. Separation between alternatives can be determined using the Euclidean distance method. A general formula for calculating separation measures can be found below.

$$A_{j^*}^{e_1} = \left\{ \frac{1}{4} \sum_{i=1}^{n} \left[\left(a_{ij}^* - a_i^+\right)^2 + \left(b_{ij}^* - b_i^+\right)^2 + \left(c_{ij}^* - c_i^+\right)^2 + \left(d_{ij}^* - d_i^+\right)^2 \right] \right\}^{\frac{1}{2}}$$

$$A_{j^-}^{e_1} = \left\{ \frac{1}{4} \sum_{i=1}^{n} \left[\left(a_{ij}^* - a_i^-\right)^2 + \left(b_{ij}^* - b_i^-\right)^2 + \left(c_{ij}^* - c_i^-\right)^2 + \left(d_{ij}^* - d_i^-\right)^2 \right] \right\}^{\frac{1}{2}}$$

Step-7: Calculate the grey relational coefficient.

Grey relation coefficient of each alternative from PIS and NIS using the following equation, respectively.

$$\gamma^+(A_{j^*}) = \frac{\min_i \min_j A_{j^*} + \zeta \max_i \max_j A_{j^*}}{A_{j^*} + \zeta \max_i \max_j A_{j^*}}$$

$$\gamma^-(A_{j^-}) = \frac{\min_i \min_j A_{j^-} + \zeta \max_i \max_j A_{j^-}}{A_{j^-} + \zeta \max_i \max_j A_{j^-}}$$

Step-8: Determine grey relation grade.

The grey relational grade of each alternativefrom PIS and NIS is determined as follows:

$$d_i^+ = \sum_{j=1}^{n} \gamma^+(A_{j^*})$$

$$d_i^- = \sum_{j=1}^{n} \gamma^-(A_{j^-})$$

Step-9: Determine closeness coefficient.

Closeness coefficient CC_i is determined from the following relation.

$$CC_i = d_i^+ / d_i^-$$

Step-10: Rank the alternatives.

Using the closeness coefficients, thealternatives can be ranked in decreasing order.

3.2 Fuzzy *Grey Relation Projection*(*FGRP*)

Step-1: Obtain the fuzzy decision matrix.

Obtain the fuzzy decision matrix as discussed in step 1 discussed in section 3.1.

Step-2: Normalize the decision matrix.

Using normalization based on three types of criteria, namely larger-the-better (benefit), smaller-the-better (cost), and nominal-the-best (optimal), the various criteria scales are transformed into comparable scales as discussed in step 2 of section 3.1.

Step-3: Obtain fuzzy positive and fuzzy negative ideal solutions.

A fuzzy positive and fuzzy negative ideal solution is determined as the referential sequence.As a result, it can be defined in terms of the following beneficial criteria:

$$\tilde{A}^+ = \left(\max_j v_{ij}\right) = \left(\tilde{v}_1^+, \tilde{v}_2^+, \ldots, \tilde{v}_m^+\right), \qquad i = 1,2,\ldots,m.$$

$$\tilde{A}^- = \left(\max_j v_{ij}\right) = \left(\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_m^-\right), \qquad i = 1,2,\ldots,m.$$

where $v_i^+ = \left(a_i^+, b_i^+, c_i^+, d_i^+\right)$ and $v_i^- = \left(a_i^-, b_i^-, c_i^-, d_i^-\right)$, $i = 1,2,\ldots,m.$

In case of cost type of criteria, the above formulae are reversed.

Step-4: Obtain separation measures from positive and negative ideal solutions.

Different separation measures are calculated for each alternative in order to determine its gray relational coefficient from PIS and NIS. The Euclidean distance method can be used to measure the distance between alternatives. As a general rule, separation measures can be calculated using the following formula.

$$A_{j^*}^{e_1} = \left\{ \frac{1}{4} \sum_{i=1}^{n} \left[\left(a_{ij}^* - a_i^+ \right)^2 + \left(b_{ij}^* - b_i^+ \right)^2 + \left(c_{ij}^* - c_i^+ \right)^2 + \left(d_{ij}^* - d_i^+ \right)^2 \right] \right\}^{\frac{1}{2}}$$

$$A_{j^-}^{e_1} = \left\{ \frac{1}{4} \sum_{i=1}^{n} \left[\left(a_{ij}^* - a_i^- \right)^2 + \left(b_{ij}^* - b_i^- \right)^2 + \left(c_{ij}^* - c_i^- \right)^2 + \left(d_{ij}^* - d_i^- \right)^2 \right] \right\}^{\frac{1}{2}}$$

Step-5: Calculate the grey relational coefficient

Grey of eachalternative from PIS and NIS are determined using the following equations, respectively.

$$\gamma^+(A_{j^*}) = \frac{\min_i \min_j A_{j^*} + \zeta \max_i \max_j A_{j^*}}{A_{j^*} + \zeta \max_i \max_j A_{j^*}}$$

$$\gamma^-(A_{j^-}) = \frac{\min_i \min_j A_{j^-} + \zeta \max_i \max_j A_{j^-}}{A_{j^-} + \zeta \max_i \max_j A_{j^-}}$$

Step-6: Obtain Relative weights of the criteria.

In this study, relative weights are obtained through CRITIC method as discussed in chapter 3

Step-7: Determine weighted grey correlation projection.

The following relationships can be used to calculate a weighted gray correlation projection onto the positive ideal solution and the negative ideal solution of alternative solutions. A weighted gray correlation projection onto a positive ideal solution is shown in the following equation.

$$p_i^+ = \sum_{j=1}^{n} \left(\bar{w}_j \times \xi_{ij}^+ \right)$$

where, $\bar{w}_j = \frac{w_j^2}{\sqrt{\sum_{j=1}^{n} w_j^2}}$.

Weighted grey correlation projection onto the negative ideal solution is shown in the following equation.

$$p_i^- = \sum_{j=1}^{n} \left(\bar{w}_j \times \xi_{ij}^- \right)$$

Step-8: Calculate the relative closeness coefficient.

The alternatives will be ranked by the value of grey correlation projection of all alternatives onto the positive ideal solution (PIS) or the projection onto the negative ideal solution (NIS). The greater the value of an alternative's projection onto PIS, the closer it is to PIS, and the better the alternative is; on the other hand, the smaller the value of its projection onto NIS, the farther it is from NIS, and the better the alternative. In order to consider both projections onto PIS and NIS adequately, relative closeness to PIS is used to rank alternatives. The relative closeness to PIS is defined as follows;

$$CC_i = \frac{p_i^+}{p_i^+ + p_i^-}$$

Step-10: Rank the alternatives.

Using the closeness coefficients, the alternatives can be ranked in decreasing order.

3.3 Illustration *of the Methodology*

The study is developed based on an empirical study of 50 alternative sites for solar power plant. In order to generate the decision matrix, the following design in design of experiments is used. The decision matrix is presented in Appendix I

Plackett-Burman Design

Factors:	20	Replicates:	1
Base runs:	50	Total runs:	50
Base blocks:	1	Total blocks:	1
Center points:	10		

The coded values obtained in the design are then converted into linguistic variables: 1-Low, 0-Medium; 1-High. These linguistic variables are transformed into triangular fuzzy numbers. The Fuzzy decision matrix so obtained is presented in Table 2.

3.3.1 Fuzzy Grey Relation Analysis Method

Fuzzy decision matrix

A fuzzy decision matrix is formulated as discussed in step 6 of section 4.4.1, and the fuzzy decision matrix so obtained is shown in Table. As illustrated in the following sections, the fuzzy gray relation analysis method proposed to rank 50 alternative sites for solar power plants is outlined. Data derived from various financial years is converted into triangular fuzzy numbers to determine the possible performance of the alternatives. In this study, minimum, average and maximum values of the criteria are considered for formulation of triangular fuzzy numbers. The fuzzy decision matrix consists of triangular fuzzy numbers and is presented in Table 2.

Normalized decision matrix

The fuzzy decision matrix is normalized as discussed in section3.1

Weighted normalized decision matrix

Weighted normalized decision matrix is obtained as discussed in section 3.1. The following relative weights of the sub criteria are considered in the study.

Table 3: Relative weights of the sub-Criteria

Sub-Criteria	Relative Weight	Sub-Criteria	Relative Weight
EC1	0.045	TE5	0.039
EC2	0.044	TE6	0.058
EC3	0.055	SP1	0.058
EC4	0.055	SP2	0.050
EC5	0.048	SP3	0.039
EC6	0.063	SP4	0.038
TE1	0.036	EV1	0.060
TE2	0.063	EV2	0.037
TE3	0.064	EV3	0.053
TE4	0.046	EV4	0.055

Fuzzy positive and fuzzy negative ideal solutions

Fuzzy positive and fuzzy negative ideal solutions are determined from the referential sequences based the type of criteria (Benefit/Cost) as discussed in section 3.1 and are p

Table 4: Fuzzy positive and fuzzy negative ideal solutions

FNIS/FPIS	EC1			EC2			EC3			EC4			EC5		
FNIS	0.0090	0.0113	0.0150	0.0088	0.0110	0.0147	0.0110	0.0138	0.0183	0.0110	0.0138	0.0183	0.0096	0.0192	0.0288
FPIS	0.0150	0.0225	0.0450	0.0147	0.0220	0.0440	0.0183	0.0275	0.0550	0.0183	0.0275	0.0550	0.0288	0.0384	0.0480
FNIS/FPIS	EC6			TE1			TE2			TE3			TE4		
FNIS	0.0126	0.0158	0.0210	0.0072	0.0144	0.0216	0.0126	0.0252	0.0378	0.0128	0.0160	0.0213	0.0092	0.0115	0.0153
FPIS	0.0210	0.0315	0.0630	0.0216	0.0288	0.0360	0.0378	0.0504	0.0630	0.0213	0.0320	0.0640	0.0153	0.0230	0.0460
FNIS/FPIS	TE5			TE6			SP1			SP2			SP3		
FNIS	0.0078	0.0156	0.0234	0.0116	0.0232	0.0348	0.0116	0.0232	0.0348	0.0100	0.0200	0.0300	0.0098	0.0195	0.0293
FPIS	0.0234	0.0312	0.0390	0.0348	0.0464	0.0580	0.0348	0.0464	0.0580	0.0300	0.0400	0.0500	0.0195	0.0293	0.0390
FNIS/FPIS	SP4			EV1			EV2			EV3			EV4		
FNIS	0.0076	0.0095	0.0127	0.0120	0.0240	0.0360	0.0074	0.0093	0.0123	0.0106	0.0133	0.0177	0.0110	0.0138	0.0183
FPIS	0.0127	0.0190	0.0380	0.0360	0.0480	0.0600	0.0123	0.0185	0.0370	0.0177	0.0265	0.0530	0.0183	0.0275	0.0550

Separation measures from positive and negative ideal solutions

The different separation measures of each alternative are calculated in order to determine the grey relational coefficient of each alternative from PIS and NIS. As discussed in section 3.1.

Grey relational coefficient

Grey of each alternative from PIS and NIS using the equation as discussed in section 3.1

Table 2: Fuzzy decision matrix

Alter-natives	Distance to the network connection			Solar Radiation			Sunshine Hours			Temperature			Wind Speed			Rain Fall			investment cost			Operation and maintenance costs			Land cost			Construction and Infrastructure cost		
	TE1			**TE2**			**TE3**			**TE4**			**TE5**			**TE6**			**EC1**			**EC2**			**EC3**			**EC4**		
Al	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5
A2	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4
A3	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5
A4	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5
A5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3
A6	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3
A7	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5
AS	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5
A9	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4
A10	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5
A11	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3
A12	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5
A13	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3
A14	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4
A15	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5
A16	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5
A17	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5
A18	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3
A19	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3
A20	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5
A21	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3

Alter-natives	Government Subsidies			Payback Period			Public Acceptance			Skilled Manpower availability			Proximity to residential areas			Population Density			Life Cycle emissions			Distance to water resource areas			Polarized light Pollution			Landscape Destruction		
	EC5			**EC6**			**SP1**			**SP2**			**SP3**			**SP4**			**EV1**			**EV2**			**EV3**			**EV4**		
Al	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5
A2	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4
A3	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3
A4	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	1	2	3
A5	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5
A6	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3
A7	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	3	4	5
AS	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5
A9	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4
A10	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	1	2	3
A11	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	1	2	3
A12	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3
A13	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5
A14	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4
A15	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5
A16	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5
A17	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5
A18	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
A19	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	1	2	3
A20	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5
A21	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5

Alter-natives	Distance to the network connection			Solar Radiation			Sunshine Hours			Temperature			Wind Speed			Rain Fall			investment cost			Operation and maintenance costs			Land cost			Construction and Infrastructure cost			Government Subsidies			Payback Period			Public Acceptance			Skilled Manpower availability			Proximity to residential areas			Population Density			Life Cycle emissions			Distance to water resource areas			Polarized light Pollution			Landscape Destruction		
	TE1			TE2			TE3			TE4			TE5			TE6			EC1			EC2			EC3			EC4			EC5			EC6			SP1			SP2			SP3			SP4			EV1			EV2			EV3			EV4		
A22	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5
A23	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	3	4	5
A24	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4
A25	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3
A26	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4
A27	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5
A28	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	1	2	3
A29	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4
A30	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	3	4	5
A31	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3
A32	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3
A33	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4
A34	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5
A35	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3
A36	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3
A37	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3
A38	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3
A39	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5
A40	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
A41	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5
A42	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	3	4	5
A43	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4
A44	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5

Alter-natives	Distance to the network connection			Solar Radiation			Sunshine Hours			Temperature			Wind Speed			Rain Fall			investment cost			Operation and maintenance costs			Land cost		
	TE1			TE2			TE3			TE4			TE5			TE6			EC1			EC2			EC3		
A45	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5
A46	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5
A47	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3	3	4	5
A48	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4
A49	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5
A50	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4

Alter-natives	Construction and Infrastructure cost			Government Subsidies			Payback Period			Public Acceptance			Skilled Manpower availability			Proximity to residential areas			Population Density			Life Cycle emissions			Distance to water resource areas			Polarized light Pollution			Landscape Destruction		
	EC4			EC5			EC6			SP1			SP2			SP3			SP4			EV1			EV2			EV3			EV4		
A45	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5
A46	1	2	3	3	4	5	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3
A47	3	4	5	3	4	5	3	4	5	1	2	3	1	2	3	3	4	5	3	4	5	1	2	3	3	4	5	3	4	5	1	2	3
A48	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4
A49	1	2	3	3	4	5	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	3	4	5	1	2	3	3	4	5	1	2	3
A50	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4

Ranking of the alternatives

A grey relational grade is computed for each alternative from PIS and NIS, and the Closeness coefficient CC_i is calculated based on the relation as described in section 3.1. The alternatives are then ranked in decreasing order using the closeness coefficients. A summary of the ranking pattern can be found in the Table 3 below.

Table 5: Ranking of alternatives

Alternatives	GRG From PIS	GRG From NIS	CC	Rank By FGRA	Alternatives	GRG From PIS	GRG From NIS	CC	Rank By FGRA
Al	14.3477	13.9873	0.4936	29	A26	10.8957	13.1698	0.5472	14
A2	10.8957	13.1698	0.5472	10	A27	11.9487	16.3863	0.5783	2
A3	14.6691	13.6659	0.4823	40	A28	14.9799	13.3551	0.4713	39
A4	12.4884	15.8465	0.5593	8	A29	10.8957	13.1698	0.5472	15
A5	13.0385	15.2965	0.5398	20	A30	13.8371	13.9328	0.5017	23
A6	12.5809	15.7541	0.5560	6	A31	14.2524	13.5174	0.4868	36
A7	14.0369	14.2981	0.5046	30	A32	16.0576	12.2774	0.4333	47
A8	11.9147	16.4203	0.5795	3	A33	10.8957	13.1698	0.5472	16
A9	10.8957	13.1698	0.5472	11	A34	14.1720	14.1630	0.4998	31
A10	12.5469	15.7881	0.5572	7	A35	14.4443	13.3255	0.4799	38
All	15.5413	12.2285	0.4404	46	A36	13.6707	14.6643	0.5175	22
A12	14.4692	13.3006	0.4790	33	A37	14.3575	13.4123	0.4830	34
A13	12.3915	15.3783	0.5538	9	A38	14.2644	13.5054	0.4863	35
A14	10.8957	13.1698	0.5472	12	A39	15.8715	11.8983	0.4285	49
A15	11.1514	16.6185	0.5984	1	A40	15.0171	13.3179	0.4700	42
A16	11.8563	16.4787	0.5816	4	A41	14.9091	12.8607	0.4631	43
A17	13.5940	14.1758	0.5105	27	A42	13.6323	14.1376	0.5091	25
A18	16.5037	11.2661	0.4057	50	A43	10.8957	13.1698	0.5472	17
A19	13.0237	14.7461	0.5310	21	A44	13.6202	14.1496	0.5095	26
A20	13.8121	13.9577	0.5026	28	A45	15.4195	12.9155	0.4558	45
A21	14.3849	13.9501	0.4923	32	A46	16.0517	12.2833	0.4335	48
A22	15.4254	12.9096	0.4556	44	A47	14.2262	13.5436	0.4877	37
A23	13.7253	14.0445	0.5057	24	A48	10.8957	13.1698	0.5472	18
A24	10.8957	13.1698	0.5472	13	A49	14.8042	13.5308	0.4775	41
A25	11.7835	15.9863	0.5757	5	A50	10.8957	13.1698	0.5472	19

3.4 Fuzzy Grey Relation Projection Method

Fuzzy decision matrix is formulated as discussed in section 3.2. The following sections describe how a fuzzy gray relation projection method is used to rank 50 alternate solar power plant sites.

3.4.1 Fuzzy positive and fuzzy negative ideal solutions

In the grey relation projection method, a normalized decision matrix is considered to find fuzzy positive and fuzzy negative ideal solutions. This is discussed in section 3.2. The fuzzy positive and negative solutions are presented in Table6.

Table 6: Fuzzy positive and negative solutions in FGP Method

FNIS/FPIS	**Criteria**														
	C1			**C2**			**C3**			**C4**			**C5**		
FNIS	0.2000	0.2500	0.3333	0.2000	0.2500	0.3333	0.2000	0.2500	0.3333	0.2000	0.2500	0.3333	0.2000	0.4000	0.6000
FPIS	0.3333	0.5000	1.0000	0.3333	0.5000	1.0000	0.3333	0.5000	1.0000	0.3333	0.5000	1.0000	0.6000	0.8000	1.0000
FNIS/FPIS	**C6**			**C7**			**C8**			**C9**			**C11**		
FNIS	0.2000	0.2500	0.3333	0.2000	0.4000	0.6000	0.2000	0.4000	0.6000	0.2000	0.2500	0.3333	0.2000	0.2500	0.3333
FPIS	0.3333	0.5000	1.0000	0.6000	0.8000	1.0000	0.6000	0.8000	1.0000	0.3333	0.5000	1.0000	0.3333	0.5000	1.0000
FNIS/FPIS	**C11**			**C12**			**C13**			**C14**			**C15**		
FNIS	0.2000	0.4000	0.6000	0.2000	0.4000	0.6000	0.2000	0.4000	0.6000	0.2000	0.4000	0.6000	0.2500	0.5000	0.7500
FPIS	0.6000	0.8000	1.0000	0.6000	0.8000	1.0000	0.6000	0.8000	1.0000	0.6000	0.8000	1.0000	0.7500	1.0000	1.2500
FNIS/FPIS	**C16**			**C17**			**C18**			**C19**			**C20**		
FNIS	0.2000	0.2500	0.3333	0.2000	0.4000	0.6000	0.2000	0.2500	0.3333	0.2000	0.2500	0.3333	0.2000	0.2500	0.3333
FPIS	0.3333	0.5000	1.0000	0.6000	0.8000	1.0000	0.3333	0.5000	1.0000	0.3333	0.5000	1.0000	0.3333	0.5000	1.0000

3.4.2Separation measures from positive and negative ideal solutions

The separation between alternatives is measured by Euclidean distance method as discussed insection 3.2.

3.4.3Grey relational coefficient

Grey relation coefficient of eachalternative from PIS and NIS are determined using the relation as discussed in section 3.2
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3.4.4 Ranking of Alternativesthrough GRP

Weighted grey correlation projections onto the positive ideal solution and the negative ideal solution of alternatives are calculated from the relations as discussed in section 3.2. Weighted grey correlation projections onto the positive ideal solution and negative ideal solution. Both projections onto PIS and NIS are used to determine relative closeness coefficients as discussed in section 3.2. The alternatives are ranked in decreasing order of relative closeness coefficient. Table 5 presents the ranking pattern.

Table 5: Ranking pattern

Alternatives	GRG From PIS	GRG From NIS	CC	Rank By GRP	Alternatives	GRG From PIS	GRG From NIS	CC	Rank By GRP
A1	0.1639	0.1477	0.4740	29	A26	0.1094	0.1410	0.5630	12
A2	0.1094	0.1410	0.5630	10	A27	0.1299	0.1817	0.5832	4
A3	0.1553	0.1563	0.5017	40	A28	0.1725	0.1391	0.4463	43
A4	0.1335	0.1781	0.5714	8	A29	0.1094	0.1410	0.5630	13
A5	0.1409	0.1707	0.5477	20	A30	0.1644	0.1472	0.4723	37
A6	0.1385	0.1731	0.5556	6	A31	0.1593	0.1523	0.4889	32
A7	0.1466	0.1650	0.5294	30	A32	0.1806	0.1310	0.4204	48
A8	0.1322	0.1794	0.5756	3	A33	0.1094	0.1410	0.5630	14
A9	0.1094	0.1410	0.5630	11	A34	0.1538	0.1578	0.5063	27
A10	0.1409	0.1707	0.5479	7	A35	0.1712	0.1404	0.4504	40
A11	0.1824	0.1292	0.4145	46	A36	0.1496	0.1620	0.5200	23
A12	0.1731	0.1385	0.4446	33	A37	0.1652	0.1464	0.4699	38
A13	0.1341	0.1775	0.5698	9	A38	0.1607	0.1509	0.4844	33
A14	0.1094	0.1410	0.5630	12	A39	0.1755	0.1361	0.4366	46
A15	0.1172	0.1944	0.6238	1	A40	0.1652	0.1464	0.4698	39
A16	0.1249	0.1867	0.5991	4	A41	0.1738	0.1378	0.4422	45
A17	0.1501	0.1615	0.5183	27	A42	0.1520	0.1596	0.5121	26
A18	0.1842	0.1274	0.4089	50	A43	0.1094	0.1410	0.5630	15
A19	0.1427	0.1689	0.5421	21	A44	0.1506	0.1610	0.5165	25
A20	0.1626	0.1490	0.4781	28	A45	0.1718	0.1398	0.4486	41
A21	0.1566	0.1550	0.4975	32	A46	0.1804	0.1312	0.4209	47
A22	0.1720	0.1396	0.4481	44	A47	0.1587	0.1529	0.4906	31
A23	0.1566	0.1550	0.4975	24	A48	0.1094	0.1410	0.5630	16
A24	0.1094	0.1410	0.5630	13	A49	0.1625	0.1491	0.4786	34
A25	0.1258	0.1857	0.5961	5	A50	0.1094	0.1410	0.5630	17

3.5 Comparison of rankings

For the evaluation and ranking of alternative solar power sites in a fuzzy environment, GRA and GRP methods are used. Table 6shows rankings by both the methods. Final ranking is obtained by taking the average closeness coefficient.

Table 6:Composite Ranking

Alternatives	Avg.CC	Rank	Alternatives	Avg.CC	Rank
A1	0.4838	36	A26	0.5551	12
A2	0.5551	8	A27	0.5808	4
A3	0.4920	28	A28	0.4588	43
A4	0.5653	6	A29	0.5551	13
A5	0.5438	20	A30	0.4870	37
A6	0.5558	18	A31	0.4878	32
A7	0.5170	22	A32	0.4269	48

Alternatives	Avg.CC	Rank	Alternatives	Avg.CC	Rank
A8	0.5776	5	A33	0.5551	14
A9	0.5551	9	A34	0.5031	27
A10	0.5526	19	A35	0.4651	40
A11	0.4274	49	A36	0.5188	23
A12	0.4618	44	A37	0.4764	38
A13	0.5618	7	A38	0.4854	33
A14	0.5551	10	A39	0.4325	46
A15	0.6111	1	A40	0.4699	39
A16	0.5903	2	A41	0.4526	45
A17	0.5144	24	A42	0.5106	26
A18	0.4073	50	A43	0.5551	15
A19	0.5366	21	A44	0.5130	25
A20	0.4904	35	A45	0.4522	41
A21	0.4949	30	A46	0.4272	47
A22	0.4519	42	A47	0.4891	31
A23	0.5016	29	A48	0.5551	16
A24	0.5551	11	A49	0.4781	34
A25	0.5859	3	A50	0.5551	17

Correlations between the ranking methods:

Correlations between ranks obtained by the proposed methods are computed. Correlation coefficient of 0.973 at p=0.000 indicates that there is strong evidence that there exists a strong correlation between the proposed methods.

Cluster Analysis:

Fifty empirical sites for location of solar power plants are analysed through cluster analysis. Average rank, Coefficient of variance is considered as cluster variables. K-means clustering algorithm is implemented through Minitab 17 and these sites are clustered into three categories (Cluster 1-Poor performance, Cluster 2-Good Performance with good consistency, Cluster 3- Good performance with less consistency). Figure 1 shows the cluster analysis.

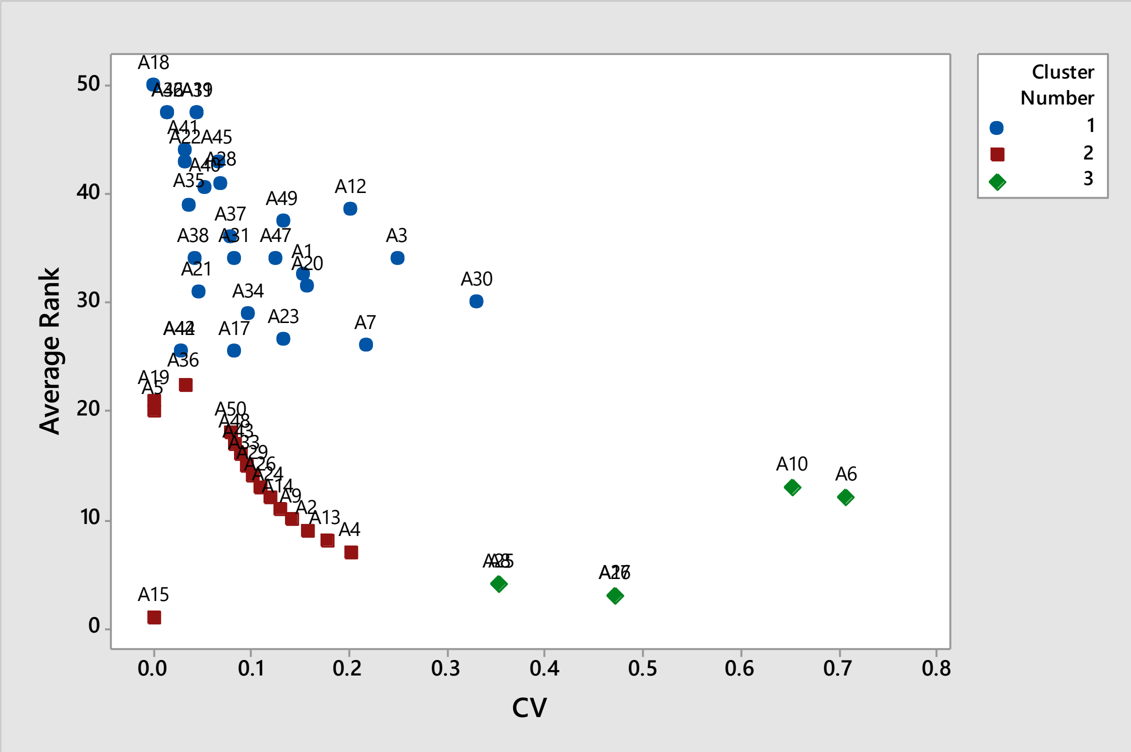

Figure 1: Cluster analysis

4.0 Concluding remarks

The proposed GRA and GRP methods in fuzzy environments provide a practical, rational, and robust tool for evaluating and ranking potential solar power plant locations.The objective of this research was to perform a performance analysis of 50 empirical sites for the location of solar power plants based on four major criteria and twenty sub-criteria, using GRA and GRP in a fuzzy environment**.** This study is one of the few attempts to evaluate the performance of sites for locating solar power plants to the best of our knowledge in fuzzy environment. It should also be noted that both GRA and GRP arrive at similar ranking patterns. There is significant correlation between the rankings obtained by GRA and GRP. The results of this study have provided useful information about competitive locations for solar power plants and are helpful to decision makers.

The proposed methodology has the advantage of being flexible. It is essential that future research be directed towards extending the proposed methodology by incorporating other uncertainty theories, such as hesitant fuzzy sets. Future research should be directed towards the development of hybrid models using traditional MCDM methods to maximize their effectiveness and rationality. This study also indicated that cluster analysis is a potent statistical tool in categorizing the performance of potential sites for location of solar power plants in specific but to any organization in analyzing their performance.

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