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Ranking of Sites of Solar Power Plants in Fuzzy Environment

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ABSTRACT

The study focuses on addressing the challenges of ranking potential sites for solar power plants in a fuzzy environment. Fuzziness arises due to the imprecision and ambiguity associated with 20 sub-criteria under for sustainable criteria. Toaddress this complex decision-making problem, Grey Relation Analysis (GRA), Grey Relation Projection (GRP), integrated Data Envelopment Analysis (DEA-GRA) and DEA-GRP are proposed in fuzzy environment. In GRA and GRP methods, ranking of alternatives is based grey relation coefficient and closeness coefficient obtained from projection values repectively to rank the alternatives. In hybrid GRA-DEA and GRP-DEA methods, additive DEA model are developed from grey relation coefficients and positive/negative grey relation coefficients respectively to rank the alternatives, aggregate rank of the alternate sites of solar power plant are arrived through half-quadratic programming approach. The outcome of this study is a robust and flexible decision support tool that allows stakeholders, including government agencies, investors, and environmentalists, to and rank potential solar power plant sites based on their specific preferences. This study contributes to the sustainable development of renewable energy by facilitating informed decision-making in the selection of solar power plant sites. By incorporating fuzziness into the site ranking process, it enhances the reliability and applicability of the results.

1. INTRODUCTION

The selection of an appropriate site for solar power plants is crucial for maximizing energy production and ensuring the economic viability of the solar power plant. This literature review aims to explore the key factors that influence the site selection process for solar power plants. By examining relevant scholarly articles and reports, this review identifies and analyzes various factors. The findings of this literature review provide valuable insights for project developers, policymakers, and researchers involved in the planning and development of solar power plants. Relevant literature review is presented in the following paragraphs.

A decision and methodology were presented by Khan and Rathi [1] to locate potential sites for large-scale solar photovoltaic (SPV) plants based on various factors such as “analysis criteria” and “exclusion criteria”.

With the aid of geographic information systems (GIS) and a multi-criterion decision-making (MCDM) technique, Al Garni and Awasthi [2] evaluated and selected the best location for utility-scale solar PV projects. Kereush and Perovych [3] proposed criteria for siting solar PV farms for analyzing available technical information in order to support a decision making process. Akkas et al. [4] considered five cities of Turkey and identified the relative ranking of these cities through ELECTRE, AHP, VIKOR and TOPSIS Methods. Sharma and Singh [5] investigated and understood the optimal site selection and efficiency for photovoltaic systems in solar laboratories and explored the possibilities for their utilization.

A combined approach of Multi Criteria Analysis (MCA) and Geographic Information Systems (GIS) was presented by Khemiri et al. [6], for the optimal placement of solar photovoltaic large farms in Makkah region in western Saudi Arabia. Wang et al. [7] illustrated FAHP, DEA and TOPSIS methods for selection of solar power plant location with a case study of Viet Nam. Authors concluded that the study is useful for location of other industries also. Using a fuzzy logic model, Yousefi et al. [8] 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).

Deveci et al. [9] 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.

Guaita-Pradas et al. [10] 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.

Ghasempour et al. [11] reviewed various criteria adopted in various MCDM methods for selection of sites for solar power plants. The authors concluded that the importance of the criteria depends on Economy, region, power network, Operating costs maintenance costs, etc. Asadi and PourHossein [12] adopted VICORE, AHP and TOPSIS for evaluation of location for construction of hybrid renewable energy power plants.

Using Geographical Information Systems (GIS) technology, Colak et al. [13] investigated the possibility of building a solar photovoltaic (PV) power plant in the Malatya Province of Turkey. Suprova et al. [14] 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.

Shimray and Malemnganbi [15] 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 in their review. They explored the ideal sites for solar power plants through MCDM approaches. The authors concluded that China, Spain, and India are best places for deployment of solar power plants.

In a paper published by Deveci et al. [16] 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 [17] 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).

Khajavipour et al. [18] considered Fourteen criteria and prioritized these criteria through integrated Delphi method and FAHP for deployment of solar power plant. Authors concluded that Distance to power lines, distance to main roads and land use were the important criteria for deployment of solar power plant. Alhammad et al. [19] 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).

Ayough et al. [20] presented a new method that integrates PROMETHEE and Interactive methods for identification of optimum location of solar power plants. The authors made sensitivity analysis to know the effectiveness of the parameters in the proposed method. Wang et al. [21] proposed Data Envelopment Analysis, Fuzzy Analytic Hierarchy Process and Fuzzy MARCOS methods for selection of solar power plants. The author illustrated the methods with a case study. The study identified three best provinces for deployment of power plant in Indonesia by considering Twenty-Three Criteria.

An Integrated Approach to Grey Relational Analysis, Analytic Hierarchy Process and Data Envelopment Analysis is proposed for in fuzzy environment for multi-attribute analysis for evaluation and selection of alternatives Pakkar [22]. Afshari Pour et al. [23] developed GIS-Fuzzy DEMATEL Model for Site Selection of Solar Power Plant and illustrated with a Case Study of Bam and Jiroft Cities of Kerman Province in Iran.

In summary, the proposed methods are valuable for ranking of solar power plant sites in a fuzzy environment because it enables systematic decision-making that considers uncertainty, multiple criteria, stakeholder preferences, and adaptability to changing conditions.

2. CRITERIA 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 criteria and sub-criteria.

2.1 Economic criteria

Economic criteria are essential considerations in the site selection of a solar power plant. Here are some key economic factors to take into account in the study.

2.1.1 Market demand and power purchase agreements (EC1)

Market demand and power purchase agreements (PPAs) are significant considerations when selecting a site for a solar power plant.

2.1.2 Investment cost (EC2)

The investment cost of a site for a solar power plant can vary significantly depending on various factors, including the size of the plant, solar technology chosen, site-specific requirements, and regional factors.

2.1.3 Return on investment (EC3)

Return on investment (ROI) is crucial considerations when selecting a site for a solar power plant. In the low range, the ROI for a solar power plant typically falls between 5% to 20%.

2.1.4 Government incentives and subsidies (EC4)

Government subsidies for solar power plants typically range from 10% to 30% of the project's total cost.

2.1.5 Utility fee of electrical energy (EC5)

Understanding the utility fees can help assess the financial viability and potential returns of the solar project.

2.1.6 Operations and maintenance costs (EC6)

The operation and maintenance (O&M) costs of a solar power plant typically include various expenses incurred during the plant's operational lifespan.

2.2 Technical criteria

Technical criteria play a crucial role in the site selection process for a solar power plant. Following are some key technical factors considered in the study.

2.2.1 Grid connection and interconnection (TE1)

Distance to the nearest electrical substation or distribution network with the availability and capacity of the grid infrastructure in the vicinity of the site is considered as measuring item.

2.2.2 Wind speed (TE2)

Wind speeds in the range of 1 to 5 meters per second (m/s) are generally considered ideal.

2.2.3 Temperature (TE3)

It can impact the performance and efficiency of solar panels, as well as the overall energy generation potential.

2.2.4 Humidity (TE4)

Humidity range values do not have a direct impact on the selection of a site for a solar power plant. Elevated humidity levels can exacerbate the impact of high temperatures on solar panel performance, reducing overall energy generation.

2.2.5 Sun shine hours (TE5)

They provide valuable information about the amount of time a location receives sunlight, which directly impacts the energy generation potential.

2.2.6 Solar radiation (TE6)

It determines the amount of solar energy available for conversion into electricity.

2.3 Sociopolitical criteria

Sociopolitical criteria are essential considerations when selecting a site for a solar power plant, as they encompass factors related to social and political aspects of the location. The following are some key sociopolitical criteria considered in the study.

2.3.1 Skilled manpower availability (SP1)

The presence of a skilled workforce can facilitate the construction, operation, and maintenance of the solar power plant.

2.3.2 Political stability and support (SP2)

They can significantly impact the project's success, regulatory compliance, and long-term operations.

2.3.3 Public acceptance (SP3)

It refers to the level of support, understanding, and approval from the local community and stakeholders regarding the establishment and operation of the solar power plant.

2.3.4 Population density (SP4)

It refers to the number of people residing within a specific area, typically measured as the number of individuals per square kilometer or square mile.

2.4 Environmental criteria

These factors encompass various aspects of the natural environment that can impact the project's feasibility, sustainability, and overall environmental impact.

2.4.1 Ecological impact (EV1)

The site is located in areas with limited biodiversity significance, no protected habitats, or minimal ecological value is considered as low level of ecological impact site.

2.4.2 Landscape destruction (EV2)

Minimal landscape destruction sites would have minimal impact on the existing landscape, with limited or no need for significant land clearing or modifications.

2.4.3 Noise and visual impact (EV3)

The solar power plant is designed and located in a way that minimizes noise emissions and integrates harmoniously into the surrounding environment.

2.4.4 Water availability (EV4)

Consider the site's proximity to water sources, such as rivers or groundwater reserves, as well as the water requirements for panel cleaning, cooling systems, and landscaping.

2.5 Alternatives

The Plackett-Burman Design of Experiments is used to generate the decision matrix of the alternatives. In this study, 50 empirical alternatives are generated for evaluation and ranking of sites for Solar power plants.

3. PROPOSED MCDM METHODS

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 methods (Grey Relation Analysis –GRA and Grey Relation Projection-GRP) and hybrid grey methods (GRA-DEA and GRP-DEA).

3.1 Grey methods

Grey methods dynamically compare each factor quantitatively, based on the level of similarity and variability among factors to establish their relation. GRA method analyzes the relational grade for discrete sequences. GRP method combined the advantages of the grey relation method and projection method.

3.1.1 Grey Relation Analysis (GRA)

The method is explained in the following steps.

Obtain the fuzzy decision matrix. Fuzzy decision matrix contains the pay-off the sub-criteria against the alternative expressed in terms of linguisticvariable. The linguistic variables are assigned with fuzzy numbers.

Obtain Crisp Decision Matrix. Conversion of Fuzzy number into crisp number is made as proposed by Afshari Pour et al. [23].

Normalize the decision matrix. Normalization based on the characteristics of three types of criteria, namely larger-the-better (benefit), smaller-the-better (cost) or nominal-the-best (optimal), is used here to transform the various criteria scales into comparable scales. Normalization formulae are presented below:

$$x_{kj} = \frac{x_{kj} - \min x_k(j)}{\max x_k(j) - \min x_k(j)} \text{ .... For benefit attribute} \quad (1)$$

$$x_{kj} = \frac{\max x_k(j) - x_{kj}}{\max x_k(j) - \min x_k(j)}$$ …. For cost attribute

where, x_{kj}=normalized value of k[th] attribute of j[th] alternative.

Determine absolute differences. The absolute difference of the compared series and the referential series should be obtained by the following the equation:

$$x_{kj}=|x_{0j}-x_{kj}| \quad (2)$$

Find out maximum and minimum absolute differences. The maximum and the minimum difference should be found from the absolute difference of the compared series and the referential series.

$$\Delta\min=\min(x_{kj});\ \Delta\max=\max(x_{kj}) \quad (3)$$

Determine grey relation coefficient. In Grey relational analysis, Grey relational coefficient ξ can be expressed as shown in equation:

$$\xi_{kj} = \frac{\Delta\min + \rho\Delta\max}{\Delta_{kj} + \rho\Delta\max} \quad (4)$$

where, Δmax: Max difference compared series and the referential series; Δmin: Max difference compared series and the referential series; ρ : Distinguishing coefficient lie between 0 and 1. Generally, the distinguishing coefficient ρ is set to 0.5.

Determine ranking of alternatives. From the grey relation coefficient, grey relation grade is determined from the following relation and the alternatives are ranked based on the descending order of grey relation grade:

$$GRG(j) = \sum_{k=1}^{n} w_k * \xi_{kj} \quad (5)$$

3.1.2 Grey Relation Projection (GRP)

The method is explained in the following steps.

Determine Positive and negative ideal Solutions. Calculate grey relation coefficient of each alternative with positive ideal solution and negative ideal solution from the following relation.

$$Q_j^+ = \sum \frac{m_k^+ + \rho * \Delta\max}{\Delta_{kj}^+ + \rho * \Delta\max};\quad \xi_{kj}^- = \frac{m_k^- + \rho * \Delta\min}{\Delta_{kj}^+ + \rho * \Delta\min} \quad (6)$$

where, mi+ and mi+ are minimum and maximum absolute differences.

Determine Grey Relation Projection. Grey Relation Projection of 'i[th]' alternative on positive (Q_j^+) and negative (Q_j^-) ideal solutions from the following relation.

$$Q_j^+ = \sum_{k=1}^{m} \frac{w_k^2 * \xi_{kj}^+}{\sqrt{\sum_{k=1}^{m} w_k^2}};\quad Q_j^- = \sum_{k=1}^{m} \frac{w_k^2 * \xi_{kj}^-}{\sqrt{\sum_{k=1}^{m} w_k^2}} \quad (7)$$

Determine Ranking of alternatives. Find relative degree of Grey Relation Projection Grade ($GRPD_j$) from the following relation. The alternatives are then ranked in decreasing order using gray relation projection grade.

$$GRPD_j = \frac{Q_j^+}{Q_j^+ + Q_j^-} \quad (8)$$

3.2 Hybrid grey methods

3.2.1 Hybrid Grey Relation Analysis and Data Envelopment Analysis (GRA-DEA)

The Hybrid GRA-DEA method is explained in the following steps:

Determine grey relation coefficient. Grey relational coefficient is determined as presented in Eq. (4).

Determine optimistic grey relation grade. Optimistic grey relation grade is obtained by solving the dual model [22] as discussed below. The model is solved through Lingo 8.0 by developing Code to the model.

Determine pessimistic grey relation grade. Pessimistic grey relation grade is obtained by solving the dual model [22] as discussed below. The model is solved by through Lingo 8.0 by developing Code to the model.

Determine normalized compromised grey relation grade. Normalized grey relation grade is obtained from the following relation.

$$\Delta_k(\beta) = \beta\frac{\Gamma_k - \Gamma_{\min}}{\Gamma_{\max} - \Gamma_{\min}} + (1-\beta)\frac{\Gamma'_k - \Gamma'_{\min}}{\Gamma'_{\max} - \Gamma'_{\min}} \quad (9)$$

where, Γ_j=Optimistic grey relation grade; Γ'_j=Pessimistic grey relation grade; Γ_{max}=max(Γ_k); Γ_{min}=min(Γ_k); Γ'_{max}=max(Γ'_k); Γ'_{min}=min(Γ'_k); $0 \le \beta \le 1$ is an adjusting parameter, which may reflect the preference of a decision-maker on the best and worst sets of weights. $\Delta_k(\beta)$ is a normalized compromise grade in the range [0,1].

Determine Ranking of alternatives. The alternatives are then ranked in decreasing order using normalized compromised gray relation grade.

3.2.2 Hybrid Grey Relation Projection and Data Envelopment Analysis (GRP-DEA)

Determine Positive and negative ideal solutions. In the Grey Relation Projection method, a normalized decision matrix is considered to find fuzzy positive and fuzzy negative ideal solutions from the following relations.

$$V_j^+ = \max(X_{kj});\ V_j^- = \min(X_{kj}) \quad (10)$$

where, X_{ij}- Elements of normalized decision matrix.

Calculation of grey relation coefficient. The grey relation coefficients of each alternative with respect to positive ideal solution and negative ideal solution are calculated from relation shown in Eq. (6).

Determine optimistic grey relation grade from positive ideal solution and negative ideal solution. Optimistic grey relation grade is obtained by solving the dual model proposed by Pakkar [22] using grey relation coefficients from positive ideal solutions and negative ideal solutions respectively. The models are solved through Lingo 8.0 by developing Code to the model.

Determine Pessimistic grey relation grade from positive ideal solution and negative ideal solution. Pessimistic grey relation grade is obtained by solving the dual model proposed by Pakkar [22] using grey relation coefficients from positive and negative ideal solutions respectively. The models are solved through Lingo 8.0 by developing Code to the model.

Determine normalized grey relation grade from positive ideal solutions. Normalized compromised grey relation grade is determined as presented in Eq. (9).

Ranking of the alternatives. The alternatives are then ranked in decreasing order using the closeness coefficients.

In sum, these methods offer a rigorous, data-driven framework for site selection, allowing for a more holistic, accurate, and future-proof decision-making process. Therefore, their use can be justified in the complex, multi-faceted task of selecting optimal sites for solar power plants.

4. RESULTS AND DISCUSSION

The proposed methods GRA, GRP, GRA-DEA and GRP-DEA are implemented as discussed in section 4 for the evaluation and ranking of 50 alternative sites for solar power plants.

The Plackett-Burman Design of Experiments is used to generate the decision matrix of the alternatives. A linguistic variable is generated for each of the sub-criteria in order to evaluate them. The linguistic scale as shown in Table 1 is used to convert the linguistic variable into fuzzy numbers. Decision matrix with linguistic variables are shown in Appendix A (Table A.1).

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)

Crisp decision matrix derived from the triangle fuzzy number Opricovic and Tzeng [24] and Normalized decision matrix are presented in Appendix (Table A.2 and Table A.3).

4.1 Relative weights of the sub-criteria (w_k)

Relative weights of the sub-criteria are considered empirically and shown in Table 2.

Table 2. Relative weights of the sub-criteria

Criteria	EC1	EC2	EC3	EC4	EC5
Relative Weights	0.036	0.063	0.064	0.046	0.039
Criteria	**EC6**	**TE1**	**TE2**	**TE3**	**TE4**
Relative Weights	0.058	0.045	0.044	0.055	0.055
Criteria	**TE5**	**TE6**	**SP1**	**SP2**	**SP3**
Relative Weights	0.048	0.063	0.058	0.05	0.039
Criteria	**SP4**	**EV1**	**EV2**	**EV3**	**EV4**
Relative Weights	0.038	0.06	0.037	0.053	0.055

4.2 Ranking

Ranking of alternative sites for solar power plants through proposed MCDM methods and are shown in Table 3.

4.2.1 Consistency across ranking methods

Alternative 4 has been consistently ranked high across all methods (Ranked 1st in GRA and GRA-DEA and within top 25 for the other methods). Alternative site 19s ranked last in all methods, implying a consensus that this is the least suitable site. Alternatives sites 32 and 34 are ranked in the top 5 across all methods.

4.2.2 Variability

Alternative site 2 shows large variability in its ranking. While GRA-DEA ranks it 6th, the GRP method ranks it 46th and alternative site 3 ranked high in GRA and GRA-DEA but much lower in GRP.

4.2.3 Medium ranking

Sites like 9, 10, 11, and 12 don't show huge variability and are situated in the middle of the rankings in most of the methods.

4.2.4 Lowest ranking

Alternative sites like 17, 27, 29, 47, and 49 consistently rank in the lower part of all methods.

4.2.5 Top ranking alternatives

Alternative sites 32 and 34 in each method shows highest rankings.

4.2.6 Outliers

Alternative site 30 is ranked 3rd in GRP-DEA but 23rd in GRA. Similarly, its position in GRP is 3rd, but 23rd in GRA-DEA. This site, in particular, has huge disparity in rankings between GRA and the other methods.

Table 3. Ranking of sites for solar power plants

Alts	GRA	GRP	GRA-DEA	GRP-DEA	Alts	GRA	GRP	GRA-DEA	GRP-DEA
1	31	18	30	18	26	29	25	28	25
2	13	46	6	35	27	48	47	48	47
3	6	39	2	30	28	39	19	36	19
4	1	11	1	23	29	49	49	49	49
5	20	14	17	11	30	23	3	18	3
6	44	30	41	31	31	28	33	22	33
7	2	10	3	12	32	4	1	4	1
8	38	37	35	37	33	46	34	44	34
9	25	24	24	17	34	5	2	5	2
10	22	32	11	28	35	42	44	39	44
11	11	7	13	8	36	21	23	23	23
12	12	27	8	32	37	45	35	46	35
13	40	22	37	21	38	24	28	26	28
14	19	16	15	20	39	32	31	38	31
15	34	38	29	33	40	15	20	21	20
16	18	5	14	5	41	14	17	20	17
17	47	48	47	47	42	17	21	25	21
18	41	26	42	26	43	7	6	9	6
19	50	50	50	50	44	27	36	31	36
20	30	29	34	38	45	8	8	12	8
21	10	12	16	13	46	33	40	33	40
22	9	9	10	15	47	26	15	27	15
23	37	41	40	43	48	35	43	32	43
24	43	42	45	45	49	3	4	7	4
25	36	45	43	46	50	16	13	19	13

Table 4. Correlation of the methods

Ranking Method	GRA	GRP	GRA-DEA	GRP-DEA
GRA	1.000	0.739 (0.00)	0.739 (0.00)	0.739 (0.00)
GRP	0.739 (0.00)	1.000	0.696 (0.00)	0.970 (0.00)
GRA-DEA	0.964 (0.00)	0.696 (0.00)	1.000	0.727 (0.00)
GRP-DEA	0.748 (0.00)	0.970 (0.00)	0.727 (0.00)	1.000

4.2.7 Correlation

Correlations between ranks obtained by the proposed methods: Correlation between the proposed methods in respect of their ranking is computed using Minitab-16. Correlation coefficients are shown in Table 4.

From the correlations between ranking methods shown in Table 4, it is observed that there is high significant positive correlation is existed between the ranking methods. The p-values for the individual hypothesis tests of the correlations are being shown in brackets. Since all the p-values are or equal to 0.00, there is sufficient evidence at α = 0.00 that there exists significant correlation between the proposed ranking methods.

4.2.8 Analysis of variance

In the ANOVA Table 5 , the p-value (1.0) for the proposed MCDM methods for ranking of sites for solar power plant indicates that there is no sufficient evidence that the ranking are not similar when alpha is set at 0.05.

Table 5. Analysis of variance

Source DF	Adj SS	Adj MS	F-Value	P-Value
Factor 3	0.5	0.18	0	1.0
Error 196	40995.3	209.16		
Total 199	40995.8			

4.3 Aggregate ranking

The Ranks obtained by the proposed methodsare aggregated to arrive the final rank through mat lab code for half-quadratic programming approach. The aggregate rank so obtained is compared with aggregate rank obtained through three-point estimate (Minimum rank+4*Average Rank +Maximum Rank)/6. Similar ranking pattern is obtained. Aggregateranks of the alternatives are presented in Table 6.

Table 6. Final ranking

Alts	Final Rank	Alts	Final Rank	Alts	Final Rank	Alts	Final Rank	Alts	Final Rank
1	25	11	8	21	12	31	30	41	15
2	26	12	19	22	10	32	1	42	21
3	18	13	31	23	43	33	41	43	5
4	7	14	16	24	46	34	2	44	32
5	14	15	35	25	45	35	44	45	6
6	38	16	9	26	28	36	23	46	37
7	4	17	47	27	48	37	42	47	20
8	39	18	36	28	29	38	27	48	40
9	22	19	50	29	49	39	34	49	3
10	24	20	33	30	11	40	17	50	13

Fuzzy MCDM methods excel at handling the uncertainties and vagueness associated with subjective human judgment. There is limited research of proposed hybrid methods (GRA-DEA and GRP-DEA) in which fuzzy logic is incorporated to deal with imprecise data.

The proposed methodology of using criteria-based ranking system for solar plant site selection provides a structured, objective, and holistic approach to decision-making. It ensures not only profitable but also sustainable, efficient, and aligned with broader social and environmental goals in deployment of solar power plants.

By meticulously ranking each site based on comprehensive criteria, planners, and decision-makers can make data-driven decisions that are not only economically sound but also socially responsible and environmentally sustainable. This multi-criteria approach ensures a more balanced and robust foundation for the critical task of selecting optimal sites for solar power plants.

5. CONCLUSIONS

The objective of this paper was to perform a performance analysis of sites for the location of solar power plants based on four major criteria and twenty sub-criteria, using GRA, GRP, GRA-DEA and GRP-DEA methods in a fuzzy environment. It is also observed that there existed high significant positive correlation in the proposed ranking methods.

The results so obtained are aggregated to arrive the final ranking. From the aggregate ranking, Top-ranked alternatives are Alternative 32 (Rank 1), Alternative 34 (Rank 2), Alternative 49 (Rank 3), Alternative 7 (Rank 4) and Alternative 43 (Rank 5). The alternatives with the highest aggregate rank values are the worst or least preferred. Alternative 19(Rank 50), Alternative 29 (Rank 49), Alternative 27 (Rank 48), Alternative 17 (Rank 47) and Alternative 24 (Rank 46).

To derive more specific reasons for the top ranking of particular alternatives, one would need to closely examine the payoff values associated with each of the 20 criteria for those alternatives, and consider the weight or importance assigned to each criterion. By doing so, you can pinpoint exactly where these alternatives are outperforming their counterparts.

This study is one of the few attempts to evaluate the performance of sites through ensemble ranking for locating solar power plants to the best of our knowledge. It should also be noted there is significant correlation between the proposed rankings. The results of this study have provided useful information about competitive locations for solar power plants and are helpful to decision makers.

The proposed methods in fuzzy environments provide a practical, rational, and robust tool for evaluating and ranking potential solar power plant locations. The proposed methodology also has the advantage of being flexible. The proposed methods may lead to an over-reliance on quantitative data might overlook qualitative aspects that could be crucial for site selection, such as community sentiment or cultural significance.

It is essential that future research be directed towards extending the proposed methodology by incorporating other uncertainty theories, such as intuitionistic and hesitant fuzzy sets. Future research should be directed towards the development of hybrid models using traditional MCDM ratio based methods to maximize their effectiveness and rationality. This study also can be extended to cluster analysis which 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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APPENDIX

Table A.1. Decision matrix with linguistic variables

Alts	EC1	EC2	EC3	EC4	EC5	EC6	TE1	TE2	TE3	TE4	TE5	TE6	SP1	SP2	SP3	SP4	EV1	EV2	EV3	EV4
A1	H	L	L	L	L	H	L	H	L	H	H	H	H	L	L	H	H	L	H	H

A2	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
A3	L	H	L	H	H	H	H	L	L	H	H	L	H	H	L	L	L	L	H	L
A4	H	L	H	H	H	H	L	L	H	H	L	H	H	L	L	L	L	H	L	L
A5	L	L	H	H	L	H	H	L	L	L	L	H	L	H	L	H	H	H	H	H
A6	H	H	L	L	H	H	L	H	H	L	L	L	L	H	L	H	L	H	H	L
A7	L	H	L	H	H	H	H	L	L	H	H	L	H	H	L	L	L	L	H	H
A8	H	H	H	H	L	L	H	H	L	H	H	L	L	L	L	H	L	H	L	H
A9	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
A10	H	H	H	H	L	L	H	H	L	H	H	L	L	L	L	H	L	H	L	L
A11	H	L	L	H	H	L	H	H	L	L	L	L	H	L	H	L	H	H	H	L
A12	L	H	H	L	L	L	L	H	L	H	L	H	H	H	H	L	L	H	H	L
A13	H	L	H	H	L	L	L	L	H	L	H	L	H	H	H	H	L	L	H	H
A14	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
A15	H	H	H	L	L	H	H	L	H	H	L	L	L	L	H	L	H	L	H	H
A16	H	L	H	H	H	H	L	L	H	H	L	H	H	L	L	L	L	H	L	H
A17	L	L	L	L	H	L	H	L	H	H	H	H	L	L	H	H	L	H	H	H
A18	H	L	H	L	H	H	H	H	L	L	H	H	L	H	H	L	L	L	L	L
A19	H	L	H	H	L	L	L	L	H	L	H	L	H	H	H	H	L	L	H	L
A20	H	H	L	H	H	L	L	L	L	H	L	H	L	H	H	H	H	L	L	H
A21	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	H
A22	L	L	H	L	H	L	H	H	H	H	L	L	H	H	L	H	H	L	L	H
A23	L	H	H	L	H	H	L	L	L	L	H	L	H	L	H	H	H	H	L	H
A24	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
A25	H	H	H	L	L	H	H	L	H	H	L	L	L	L	H	L	H	L	H	L
A26	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
A27	H	H	L	L	H	H	L	H	H	L	L	L	L	H	L	H	L	H	H	H
A28	H	L	L	L	L	H	L	H	L	H	H	H	H	L	L	H	H	L	H	L
A29	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
A30	L	H	H	L	L	L	L	H	L	H	L	H	H	H	H	L	L	H	H	H
A31	L	L	L	H	L	H	L	H	H	H	H	L	L	H	H	L	H	H	L	L
A32	L	L	H	L	H	L	H	H	H	H	L	L	H	H	L	H	H	L	L	L
A33	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
A34	L	H	H	H	H	L	L	H	H	L	H	H	L	L	L	L	H	L	H	H
A35	H	H	L	H	H	L	L	L	L	H	L	H	L	H	H	H	H	L	L	L
A36	L	L	H	H	L	H	H	L	L	L	L	H	L	H	L	H	H	H	H	L
A37	L	H	H	L	H	H	L	L	L	L	H	L	H	L	H	H	H	H	L	L
A38	L	H	L	H	L	H	H	H	H	L	L	H	H	L	H	H	L	L	L	L
A39	H	L	H	L	H	H	H	H	L	L	H	H	L	H	H	L	L	L	L	H
A40	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
A41	H	L	L	H	H	L	H	H	L	L	L	L	H	L	H	L	H	H	H	H
A42	L	H	L	H	L	H	H	H	H	L	L	H	H	L	H	H	L	L	L	H
A43	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
A44	L	L	L	H	L	H	L	H	H	H	H	L	L	H	H	L	H	H	L	H
A45	H	H	L	L	L	L	H	L	H	L	H	H	H	H	L	L	H	H	L	H
A46	H	H	L	L	L	L	H	L	H	L	H	H	H	H	L	L	H	H	L	L
A47	L	L	L	L	H	L	H	L	H	H	H	H	L	L	H	H	L	H	H	L
A48	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
A49	L	H	H	H	H	L	L	H	H	L	H	H	L	L	L	L	H	L	H	L
A50	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M

Table A.2. Decision matric with crisp data

Alternatives	EC1	EC2	EC3	EC4	EC5	EC6	TE1	TE2	TE3	TE4	TE5	TE6	SP1	SP2	SP3	SP4	EV1	EV2	EV3	EV4
A1	3.93	2.07	2.07	2.07	2.07	3.93	2.07	3.93	2.07	3.93	3.93	3.93	3.93	2.07	2.07	3.93	3.93	2.07	3.93	3.93
A2	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
A3	4.80	4.73	4.27	4.73	4.73	6.20	4.73	4.80	4.27	6.20	6.20	4.80	6.20	4.73	4.27	4.80	4.80	4.27	6.20	4.80
A4	1.47	0.53	1.47	1.47	1.47	1.47	0.53	0.53	1.47	1.47	0.53	1.47	1.47	0.53	0.53	0.53	0.53	1.47	0.53	0.53
A5	3.27	1.80	1.73	3.20	1.80	5.20	3.20	3.27	1.27	3.80	3.80	3.73	3.80	3.20	1.27	3.73	3.73	1.73	5.20	3.73
A6	4.20	2.73	2.80	2.80	4.20	4.20	2.27	2.73	4.20	2.80	2.27	2.80	2.80	2.73	2.27	2.73	2.27	4.20	2.73	2.27
A7	1.27	3.73	1.80	5.20	3.73	5.20	5.20	1.27	1.27	3.73	3.73	1.80	3.73	5.20	1.27	1.80	1.80	1.80	5.20	3.20
A8	5.20	3.20	3.73	3.73	3.80	3.80	1.73	3.20	3.80	3.73	1.73	3.27	3.27	1.80	1.27	3.20	1.27	5.20	1.80	1.73
A9	1.50	2.50	3.50	4.50	2.50	4.50	4.50	1.50	1.50	2.50	2.50	3.50	2.50	4.50	1.50	3.50	3.50	3.50	4.50	4.50
A10	5.20	5.20	3.20	3.20	3.27	3.27	3.20	5.20	3.27	3.20	3.20	1.27	1.27	3.27	1.27	5.20	1.27	5.20	3.27	1.80
A11	2.47	3.53	1.53	4.47	4.47	3.53	4.47	2.47	1.53	3.53	3.53	1.53	4.47	3.53	2.47	1.53	2.47	2.47	4.47	3.53

A12	3.80	5.20	5.20	3.80	1.27	1.27	3.80	5.20	1.27	5.20	3.80	1.73	1.73	1.73	1.73	3.80	1.27	5.20	1.73	3.27
A13	4.20	2.27	2.73	4.20	2.80	2.27	2.80	2.80	2.73	2.27	2.73	2.27	4.20	2.73	4.20	2.73	2.80	2.80	4.20	2.73
A14	3.50	4.50	4.50	3.50	1.50	1.50	3.50	4.50	1.50	4.50	3.50	2.50	2.50	2.50	2.50	3.50	1.50	4.50	2.50	1.50
A15	5.20	1.73	3.20	3.80	3.27	1.73	3.73	3.27	3.20	1.73	1.80	1.27	3.80	1.80	5.20	1.80	3.73	3.27	5.20	3.20
A16	2.47	3.53	4.47	2.47	2.47	2.47	1.53	3.53	2.47	4.47	1.53	4.47	4.47	3.53	3.53	1.53	1.53	4.47	3.53	2.47
A17	3.80	1.80	3.80	3.27	1.73	1.80	3.20	1.27	5.20	3.20	3.73	1.73	3.27	3.27	5.20	3.73	1.80	1.73	5.20	5.20
A18	4.20	2.27	4.20	2.80	4.20	4.20	2.73	2.73	2.80	2.80	2.73	4.20	2.80	2.73	2.73	2.27	2.27	2.80	2.27	2.80
A19	3.73	3.27	3.73	1.73	1.80	3.27	3.80	1.27	5.20	3.80	3.20	1.80	1.73	1.73	5.20	3.20	3.27	1.80	5.20	3.80
A20	5.20	1.73	3.80	3.73	5.20	3.80	1.80	1.80	3.27	3.73	1.80	5.20	3.27	3.20	3.20	1.73	1.73	3.27	1.27	3.73
A21	1.80	1.27	1.80	1.80	3.27	1.27	3.27	1.27	3.80	3.27	3.80	3.27	1.80	1.80	3.80	3.80	1.27	3.27	3.80	3.73
A22	3.80	1.80	3.73	1.80	5.20	3.27	3.73	3.73	1.73	3.20	3.27	3.80	1.73	5.20	3.80	3.20	3.20	1.27	1.27	3.20
A23	3.27	1.73	3.73	3.27	1.73	1.73	1.27	1.27	3.27	1.27	3.73	1.27	3.73	3.27	3.73	3.73	1.73	1.73	3.27	3.20
A24	3.50	3.50	2.50	3.50	4.50	1.50	2.50	2.50	2.50	4.50	1.50	3.50	2.50	4.50	3.50	4.50	4.50	1.50	1.50	4.50
A25	1.73	3.20	3.20	1.27	1.80	3.20	1.73	1.27	1.73	1.73	1.80	1.27	1.80	1.27	3.20	1.80	3.20	1.80	1.73	3.80
A26	2.00	2.00	4.00	2.00	4.00	2.00	4.00	4.00	4.00	4.00	2.00	2.00	4.00	4.00	2.00	4.00	4.00	2.00	2.00	4.00
A27	3.20	5.20	3.80	1.27	3.73	5.20	1.80	1.73	3.20	1.80	3.27	1.27	3.27	1.73	3.80	3.73	3.80	3.73	3.20	3.73
A28	3.47	2.53	2.53	2.53	2.53	3.47	2.53	3.47	2.53	3.47	3.47	3.47	3.47	2.53	2.53	3.47	3.47	2.53	3.47	2.53
A29	4.50	4.50	3.50	1.50	2.50	4.50	3.50	2.50	4.50	3.50	1.50	1.50	1.50	2.50	3.50	2.50	3.50	2.50	4.50	2.50
A30	2.80	2.73	2.73	2.27	2.27	2.80	2.27	4.20	2.27	4.20	2.80	4.20	4.20	2.73	2.73	2.80	2.80	2.73	4.20	2.73
A31	3.53	3.53	1.53	2.47	3.53	4.47	1.53	4.47	4.47	2.47	2.47	1.53	1.53	4.47	2.47	3.53	2.47	4.47	3.53	3.53
A32	3.27	1.80	3.20	1.27	1.73	3.27	1.73	5.20	1.73	5.20	3.27	3.80	5.20	3.20	1.80	3.73	3.73	1.80	3.80	1.80
A33	2.50	2.50	2.50	3.50	2.50	3.50	2.50	3.50	3.50	3.50	3.50	2.50	2.50	3.50	3.50	2.50	3.50	3.50	2.50	2.50
A34	1.27	3.73	5.20	1.73	3.20	1.27	1.80	5.20	3.20	3.80	1.73	3.73	3.80	3.80	3.27	1.80	3.20	3.27	3.73	3.73
A35	2.47	2.47	1.53	4.47	2.47	3.53	1.53	3.53	3.53	4.47	3.53	2.47	1.53	4.47	4.47	2.47	4.47	3.53	1.53	1.53
A36	1.27	1.80	5.20	3.20	3.80	1.73	3.73	3.80	3.80	3.27	1.80	3.20	3.27	3.73	1.27	3.73	5.20	1.73	3.20	1.80
A37	2.80	4.20	2.73	2.80	4.20	2.73	2.27	2.27	2.27	2.80	2.73	2.80	2.73	2.80	4.20	4.20	4.20	2.73	2.27	2.27
A38	1.27	3.73	3.80	5.20	3.27	3.20	3.20	3.73	3.73	1.27	3.27	5.20	1.73	1.80	1.73	3.20	3.80	1.80	3.80	3.27
A39	3.73	3.80	3.20	3.27	5.20	3.20	1.73	1.73	1.27	3.27	3.20	3.73	1.80	3.73	5.20	3.80	3.80	1.80	1.27	1.73
A40	1.27	1.80	3.27	3.80	1.27	3.80	3.80	1.80	1.80	1.27	1.27	3.80	1.80	3.27	1.80	3.80	3.27	3.27	3.27	1.27
A41	3.20	3.27	3.80	1.73	5.20	3.80	3.20	3.20	1.27	1.27	3.80	1.80	3.73	1.80	5.20	3.27	3.73	3.73	1.73	3.20
A42	1.27	3.73	1.27	3.73	1.27	3.73	3.73	3.73	3.73	1.27	1.27	3.73	3.73	1.27	3.73	3.73	1.27	1.27	1.27	1.73
A43	4.50	1.50	3.50	2.50	4.50	3.50	4.50	4.50	1.50	1.50	3.50	3.50	2.50	3.50	4.50	1.50	2.50	2.50	2.50	4.50
A44	1.27	1.80	1.27	3.20	1.27	3.20	1.80	3.20	3.20	1.73	1.73	1.80	1.80	1.73	3.20	1.80	1.73	1.73	1.27	3.20
A45	4.47	2.47	1.53	3.53	3.53	1.53	4.47	3.53	2.47	1.53	2.47	2.47	4.47	2.47	3.53	1.53	4.47	4.47	3.53	4.47
A46	1.73	3.73	1.27	3.80	1.27	3.80	3.73	3.80	5.20	1.80	3.20	3.73	3.73	3.20	3.80	3.27	3.20	3.20	1.27	3.80
A47	2.80	2.80	2.27	2.27	2.73	2.27	4.20	2.27	4.20	2.73	4.20	4.20	2.80	2.80	2.73	2.73	2.80	4.20	2.73	2.80
A48	2.50	2.50	1.50	3.50	1.50	3.50	2.50	3.50	4.50	3.50	4.50	2.50	2.50	4.50	3.50	1.50	4.50	4.50	1.50	3.50
A49	3.27	3.73	1.73	1.73	3.20	1.27	3.80	1.73	5.20	1.80	5.20	5.20	3.27	3.27	1.80	1.80	3.73	3.80	3.20	3.27
A50	4.00	4.00	2.00	2.00	2.00	2.00	4.00	2.00	4.00	2.00	4.00	4.00	4.00	4.00	2.00	2.00	4.00	4.00	2.00	2.00

Table A.3. Normalized decision matrix

Alternatives	EC1	EC2	EC3	EC4	EC5	EC6	TE1	TE2	TE3	TE4	TE5	TE6	SP1	SP2	SP3	SP4	EV1	EV2	EV3	EV4
A1	0.32	0.67	0.80	0.80	0.20	0.46	0.33	0.73	0.80	0.46	0.60	0.68	0.54	0.33	0.67	0.27	0.27	0.20	0.60	0.27
A2	0.05	0.04	0.05	0.05	0.95	0.24	0.96	0.96	0.05	0.24	0.79	0.95	0.76	0.96	0.04	0.04	0.04	0.95	0.79	0.04
A3	0.10	0.10	0.24	0.12	0.88	0.00	0.90	0.91	0.24	0.00	1.00	0.90	1.00	0.90	0.20	0.09	0.09	0.76	1.00	0.09
A4	0.95	1.00	0.95	0.95	0.05	0.96	0.00	0.00	0.95	0.96	0.00	0.05	0.04	0.00	1.00	1.00	1.00	0.05	0.00	1.00
A5	0.49	0.73	0.88	0.51	0.14	0.20	0.57	0.59	1.00	0.49	0.58	0.63	0.51	0.57	0.84	0.31	0.31	0.12	0.82	0.31
A6	0.25	0.53	0.61	0.61	0.75	0.41	0.37	0.47	0.25	0.69	0.31	0.39	0.31	0.47	0.63	0.53	0.63	0.75	0.39	0.63
A7	1.00	0.31	0.86	0.00	0.63	0.20	1.00	0.16	1.00	0.50	0.56	0.14	0.50	1.00	0.84	0.73	0.73	0.14	0.82	0.43
A8	0.00	0.43	0.37	0.37	0.64	0.49	0.26	0.57	0.36	0.50	0.21	0.51	0.41	0.27	0.84	0.43	0.84	1.00	0.22	0.74
A9	0.94	0.58	0.43	0.18	0.31	0.34	0.85	0.21	0.94	0.75	0.35	0.57	0.25	0.85	0.79	0.36	0.36	0.57	0.70	0.15
A10	0.00	0.00	0.51	0.51	0.51	0.59	0.57	1.00	0.49	0.61	0.47	0.00	0.00	0.59	0.84	0.00	0.84	1.00	0.48	0.73
A11	0.69	0.36	0.93	0.19	0.81	0.54	0.84	0.41	0.93	0.54	0.53	0.07	0.65	0.64	0.59	0.79	0.59	0.31	0.69	0.36
A12	0.36	0.00	0.00	0.36	0.00	1.00	0.70	1.00	1.00	0.20	0.58	0.12	0.09	0.26	0.74	0.30	0.84	1.00	0.21	0.41
A13	0.25	0.63	0.63	0.25	0.39	0.80	0.49	0.49	0.63	0.80	0.39	0.25	0.59	0.47	0.21	0.53	0.51	0.39	0.65	0.53
A14	0.43	0.15	0.18	0.43	0.06	0.95	0.64	0.85	0.94	0.34	0.52	0.31	0.25	0.42	0.58	0.36	0.79	0.82	0.35	0.79
A15	0.00	0.74	0.51	0.36	0.51	0.91	0.69	0.59	0.51	0.91	0.22	0.00	0.51	0.27	0.00	0.73	0.31	0.51	0.82	0.43
A16	0.69	0.36	0.19	0.69	0.31	0.76	0.21	0.64	0.69	0.35	0.18	0.81	0.65	0.64	0.36	0.79	0.79	0.81	0.53	0.59
A17	0.36	0.73	0.36	0.49	0.12	0.89	0.57	0.16	0.00	0.61	0.56	0.12	0.41	0.59	0.00	0.31	0.73	0.12	0.82	0.00
A18	0.25	0.63	0.25	0.61	0.75	0.41	0.47	0.47	0.61	0.69	0.39	0.75	0.31	0.47	0.53	0.63	0.63	0.39	0.31	0.51
A19	0.37	0.41	0.37	0.88	0.14	0.59	0.70	0.16	0.00	0.49	0.47	0.14	0.09	0.26	0.00	0.43	0.41	0.14	0.82	0.30
A20	0.00	0.74	0.36	0.37	1.00	0.49	0.27	0.27	0.49	0.50	0.22	1.00	0.41	0.57	0.43	0.74	0.74	0.51	0.13	0.31
A21	0.86	0.84	0.86	0.86	0.51	1.00	0.59	0.16	0.36	0.59	0.58	0.51	0.11	0.27	0.30	0.30	0.84	0.51	0.58	0.31

A22	0.36	0.73	0.37	0.86	1.00	0.59	0.69	0.69	0.88	0.61	0.48	0.64	0.09	1.00	0.30	0.43	0.43	0.00	0.13	0.43
A23	0.49	0.74	0.37	0.49	0.12	0.91	0.16	0.16	0.49	1.00	0.56	0.00	0.50	0.59	0.31	0.31	0.74	0.12	0.48	0.43
A24	0.43	0.36	0.69	0.43	0.82	0.95	0.42	0.42	0.69	0.34	0.17	0.57	0.25	0.85	0.36	0.15	0.15	0.06	0.17	0.15
A25	0.88	0.43	0.51	1.00	0.14	0.61	0.26	0.16	0.88	0.91	0.22	0.00	0.11	0.16	0.43	0.73	0.43	0.14	0.21	0.30
A26	0.81	0.69	0.31	0.81	0.69	0.85	0.74	0.74	0.31	0.45	0.26	0.19	0.55	0.74	0.69	0.26	0.26	0.19	0.26	0.26
A27	0.51	0.00	0.36	1.00	0.63	0.20	0.27	0.26	0.51	0.89	0.48	0.00	0.41	0.26	0.30	0.31	0.30	0.63	0.47	0.31
A28	0.44	0.57	0.68	0.68	0.32	0.55	0.43	0.63	0.68	0.55	0.52	0.56	0.45	0.43	0.57	0.37	0.37	0.32	0.52	0.57
A29	0.18	0.15	0.43	0.94	0.31	0.34	0.64	0.42	0.18	0.55	0.17	0.06	0.05	0.42	0.36	0.58	0.36	0.31	0.70	0.58
A30	0.61	0.53	0.63	0.75	0.25	0.69	0.37	0.79	0.75	0.41	0.40	0.75	0.59	0.47	0.53	0.51	0.51	0.37	0.65	0.53
A31	0.42	0.36	0.93	0.69	0.58	0.35	0.21	0.84	0.19	0.76	0.34	0.07	0.05	0.84	0.59	0.36	0.59	0.81	0.53	0.36
A32	0.49	0.73	0.51	1.00	0.12	0.59	0.26	1.00	0.88	0.20	0.48	0.64	0.80	0.57	0.73	0.31	0.31	0.14	0.58	0.73
A33	0.69	0.58	0.69	0.43	0.31	0.55	0.42	0.64	0.43	0.55	0.52	0.31	0.25	0.64	0.36	0.58	0.36	0.57	0.35	0.58
A34	1.00	0.31	0.00	0.88	0.49	1.00	0.27	1.00	0.51	0.49	0.21	0.63	0.51	0.70	0.41	0.73	0.43	0.51	0.56	0.31
A35	0.69	0.59	0.93	0.19	0.31	0.54	0.21	0.64	0.42	0.35	0.53	0.31	0.05	0.84	0.16	0.59	0.16	0.58	0.18	0.79
A36	1.00	0.73	0.00	0.51	0.64	0.91	0.69	0.70	0.36	0.59	0.22	0.49	0.41	0.69	0.84	0.31	0.00	0.12	0.47	0.73
A37	0.61	0.21	0.63	0.61	0.75	0.70	0.37	0.37	0.75	0.69	0.39	0.39	0.30	0.49	0.21	0.21	0.21	0.37	0.31	0.63
A38	1.00	0.31	0.36	0.00	0.51	0.61	0.57	0.69	0.37	1.00	0.48	1.00	0.09	0.27	0.74	0.43	0.30	0.14	0.58	0.41
A39	0.37	0.30	0.51	0.49	1.00	0.61	0.26	0.26	1.00	0.59	0.47	0.63	0.11	0.69	0.00	0.30	0.30	0.14	0.13	0.74
A40	1.00	0.73	0.49	0.36	0.00	0.49	0.70	0.27	0.86	1.00	0.13	0.64	0.11	0.59	0.73	0.30	0.41	0.51	0.48	0.84
A41	0.51	0.41	0.36	0.88	1.00	0.49	0.57	0.57	1.00	1.00	0.58	0.14	0.50	0.27	0.00	0.41	0.31	0.63	0.21	0.43
A42	1.00	0.31	1.00	0.37	0.00	0.50	0.69	0.69	0.37	1.00	0.13	0.63	0.50	0.16	0.31	0.31	0.84	0.00	0.13	0.74
A43	0.18	0.79	0.43	0.69	0.82	0.55	0.85	0.85	0.94	0.95	0.52	0.57	0.25	0.64	0.15	0.79	0.58	0.31	0.35	0.15
A44	1.00	0.73	1.00	0.51	0.00	0.61	0.27	0.57	0.51	0.91	0.21	0.14	0.11	0.26	0.43	0.73	0.74	0.12	0.13	0.43
A45	0.19	0.59	0.93	0.42	0.58	0.95	0.84	0.64	0.69	0.95	0.34	0.31	0.65	0.41	0.36	0.79	0.16	0.81	0.53	0.16
A46	0.88	0.31	1.00	0.36	0.00	0.49	0.69	0.70	0.00	0.89	0.47	0.63	0.50	0.57	0.30	0.41	0.43	0.49	0.13	0.30
A47	0.61	0.51	0.75	0.75	0.37	0.80	0.79	0.37	0.25	0.70	0.65	0.75	0.31	0.49	0.53	0.53	0.51	0.75	0.39	0.51
A48	0.69	0.58	0.94	0.43	0.06	0.55	0.42	0.64	0.18	0.55	0.70	0.31	0.25	0.85	0.36	0.79	0.15	0.82	0.17	0.36
A49	0.49	0.31	0.88	0.88	0.49	1.00	0.70	0.26	0.00	0.89	0.82	1.00	0.41	0.59	0.73	0.73	0.31	0.64	0.47	0.41
A50	0.31	0.26	0.81	0.81	0.19	0.85	0.74	0.31	0.31	0.85	0.61	0.69	0.55	0.74	0.69	0.69	0.26	0.69	0.26	0.69