Using Multi-Criteria Decision Making (MCDM) and Choosing by Advantages (CBA) to Determine the Optimal Location for Solar Photovoltaic (PV) Farms

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Abstract

Solar energy is a critical component of the energy development strategy. The location of solar photovoltaic (PV) plants has a significant impact on the cost of power production. A favorable situation would result in significant cost savings and increased electricity generation efficiency. California is located in the United States of America's southwest region, a place blessed with an abundance of solar energy. In recent years, the state's economy and population have expanded quickly, resulting in increased need for power. The study examines south of California for an area that is well-suited for the building of large photovoltaic (PV) plants to meet local electricity needs. To begin, this article imposed some limits on the selection of three potential solar project locations (S1, S2, and S3). Then, a more systematic approach to solar plant site selection was presented, focusing on five major characteristics (economic, technological, social, geographical, and environmental). This is the first time that the Choosing by Advantages (CBA) approach has been used to determine the locations of photovoltaic (PV) plants, with possible locations ranked S2>S1>S3. It was compared to more classic methodologies such as Multi-Criteria Decision Making (MCDM). The findings of this study suggest that the CBA strategy not only streamlines the solar plant selection process, but also more closely aligns with the objectives and desires of investors.

Introduction

Historically, non-renewable energy sources such as fossil fuels were heavily relied upon. However, its usage results in an increase in harmful gas emissions, which has a detrimental effect on the long-term growth of society\(^1\). By contrast, renewable energy is vital for society's long-term growth. Solar energy is gaining prominence as a cost-effective and endless source of renewable energy\(^2\). Solar energy generation has also grown significantly due to its benefits, which include ease of maintenance, low environmental effect, and a longer service life. Solar energy output is predicted to develop significantly in the near future, particularly in industrial areas such as California, which has the world's fifth-largest economy\(^3\). California has huge potential for solar power generation. Governor Jerry Brown signed a bill setting the electricity target into law in 2018. California is required by law to generate 50% of its electricity from renewable sources by 2025, 60% by 2030, and 100% zero-carbon electricity by 2045\(^4\). This bill has advanced California's renewable energy growth. According to the California Energy Commission's report, California became the first state in the United States in 2014 to generate more than 5% of its utility-scale electricity from solar energy, increasing to 14% in 2019\(^5\). With the addition of small-scale solar, the state generates a fifth of its overall electricity needs\(^6\). California generated 40% of the nation's solar photovoltaic energy and 70% of utility-scale solar thermal energy in 2019\(^7\). By November 2020, California would have approximately 13,000 megawatts of utility-scale solar capacity, the most of any state in USA\(^8\). California would roughly triple its existing electrical grid capacity and maintain a record rate of renewable energy capacity expansion over the next 25 years to fulfill the 2045 target while also powering other sectors and achieving the state's economy-wide climate goals\(^9\). This suggests that solar energy project construction in California will expand during the next decade.
Solar project development is contingent upon the location of construction sites. Choosing appropriate locations for large solar energy systems has a substantial impact on the amount and quality of solar energy generated\(^1\). Additionally, investors would profit economically and socially from a favorable geographic location for investment. However, due to the inherent environmental limits and conflicts, locating an appropriate location for solar power plants in California presents certain obstacles. This is because California includes a variety of varied terrains, including deserts and coastlines; however, population distribution will also affect the accuracy of site selection. As a result, it is required to develop a new model and process for site selection that is tailored to the peculiarities of California.

The purpose of this study is to make a contribution to the field of solar site selection. It is mostly used in California to determine the most cost-effective solar energy installations. Then, to close the research gap in California, a significantly more trustworthy model for solar plant site selection is offered. The following summarizes the work's key contributions:

1. To meet California's energy needs, it is vital to develop a sustainable energy supply position.
2. This is the first time that the method of choosing by advantages (CBA) has been used to select locations for large solar photovoltaic (PV) plants. It instills a new way of thinking in decision makers.
3. To provide a more specific and methodical framework for solar plant site selection, it includes five basic criteria: economic, technological, social, geographical, and environmental, as well as various sub-criteria for each primary criterion.

The remainder of the study is divided into the following sections: Section 2 provides an outline of how MCDM is used to select solar plant locations. Section 3 examines the criteria, parameters, and model for solar power plant location; it also includes specifics on the CBA approach. Section 4 discusses the conclusions and the CBA sensitivity analysis. Finally, section 5 interprets the paper's conclusion.

**Literature Review**

Due to the complexity of solar power station location selection and the numerous elements that may influence it, researchers may consider using multi-criteria decision making to make a location an option during the study process. MCDM is a well-known decision approach in operations research that encompasses a variety of techniques. Among the most often used are the analytic hierarchy process (AHP), the preference rating organization system for enrichment evaluations (PROMETHEE), and multi-attribute utility theory (MAUT)\(^1\). These methods are capable of analyzing and evaluating discrepancies between criteria and decision maker's opinions\(^2\).

Multi-criteria analysis has been effectively utilized internationally in the field of solar plant site selection due to this property. Dejan Doljak et al. identified suitable locations for solar energy production in Serbia using the spatial suitability index\(^3\). H. Ebru Colak et al. used the AHP technique to discover the ideal location for a solar farm in Turkey's Malatya province, with the majority of environmental, topographical, and technological factors taken into account\(^4\). D. Kereush et al. established evaluation and exclusion
criteria and then used the AHP approach to ascertain the feasibility of constructing a solar energy plant in Ukraine\textsuperscript{15}. AHP is the principal decision-making technique utilized in these researches to identify solar photovoltaic (PV) sites. AHP, on the other hand, is unable to fully address the issue of mutual influence between elements throughout the site selection process. Thus, J. M. Sánchez-Lozano et al. successfully applied GIS and the TOPSIS technique to investigate potential solar plant locations in south-eastern Spain\textsuperscript{16}. Similarly, Mahmood Zoghi et al.\textsuperscript{17} used fuzzy logic and weighted linear combination (WLC) to resolve conflicting elements and determine the optimal location for solar energy development in Iran.

Indeed, the vast bulk of the literature in the subject of solar energy site selection employs classic MCDM techniques. However, these approaches are incapable of comprehending the subjectivity of input assumptions or minimizing the effect of decision makers' opinions on the outcome.

On the other hand, Yunna Wu et al.\textsuperscript{18} established a novel site selection model and used the PROMETHEE technique to determine the ideal location for a parabolic trough concentrating solar power plant in China. This concept addressed the problem of insufficient information being available throughout the site selection process. However, the site selection criteria are not thoroughly considered. Similarly, Shaimaa Magdy Habib used only two criteria – technical and economic – to locate solar plants on Egypt's northwest coast, utilizing remote sensing (RS) and AHP techniques\textsuperscript{19}. H.S. Ruiz et al. considered climate, geography, and technical factors in selecting the ideal place for solar energy installation in Indonesia, but ignored local economic and social development.\textsuperscript{20} As illustrated in Table 1, present researches on solar site selection frequently overlook social aspects, which is irrational. Social factors significantly affect the investment and benefit of a project. Taking into account social factors is crucial for promoting sustainable development.
## Table 1
Optimal site selection for solar plant in different regions.

| Authors            | Criteria                                      | MCDM methods          |
|--------------------|-----------------------------------------------|-----------------------|
| Dejan Doljak et al | Climate, Orography, Vegetation                | AHP                   |
| H. Ebru Colak et al| Environmental, Location, Technical            | AHP;                 |
| D. Kereush et al   | Location, Orography                           | AHP                   |
| JM. S-Lozano et al | Environmental, Geographical, Location, Climatic| AHP-TOPSIS            |
| Mahmood Zoghi      | Environmental, Location, Orography, Climate    | Fuzzy logic and WLC   |
| Yunna Wu et al     | Economy, technical, Environmental, social     | Fuzzy PROMETHEE       |
| S Magdy Habib et al| Economy, technical                           | AHP                   |
| H.S. Ruiz et al    | Environmental, Location, Orography, Climate    | AHP                   |

As a result, it is essential to alter traditional perspective and devise a new approach for overcoming these disadvantages. Choosing by Advantages is a lean decision-making method built by Suhr in 1999 that supports sound decision-making using alternative advantage comparisons\(^2\). It can convert qualitative aspects to quantitative ones in order to mitigate subjective effect caused by the relative benefits of various factors. Due to the CBA method's superior performance in terms of optimal project selection, it has been widely adopted in the architectural, engineering, and construction (AEC) business\(^2\)\(^{-}\)\(^{26}\). Based on these features, the CBA technique is deemed suitable for solar energy site selection. To demonstrate CBA's superiority, this article also employs two standard multi-criteria decision-making methodologies. TOPSIS and PROMETHEE are used to conduct comparative analyses.

## Methodology

### 3.1 Establish the criteria and variables

Following a comprehensive review of the relevant literature and consultation with industry experts, this paper suggests sixteen essential site selection considerations. However, at some point throughout the site selection process, the characteristics of variables may have an effect on the output's accuracy. To ideally solve this problem, the variables in this study can be classified as useful or negative, based on whether or not to enhance photovoltaic power plant production as their values increase. Visual impact, solar irradiation potential, land types, geological disaster, policies, public attitude, and local development planning are considered beneficial criteria in this paper; payback period, investment cost, rainfall,
temperature, humidity, distance to roads, distance to substations, and population density are considered detrimental criteria. This treatment would advocate for simplifying the MCDM model and outlining the CBA model's decision rules. The justification and explanation for the selection of each factor will be discussed in greater detail below:

**Visual impact**

The building of solar farms would have an effect on the daily life of animals and humans\(^\text{27}\). To maintain the long-term viability of the ecosystem, the visual impact of the solar farm must be considered throughout the design stage.

**Solar irradiation potential**

It's fair to say that this is a key indicator for whether solar farms will be built. Solar farms' ability to produce and save money is directly impacted by the amount of available solar energy. The more solar radiation there is, the more electricity is generated, and the more efficient the electric field is\(^\text{28}\).

**Land types**

In some places, land types and availability might be a factor in determining the location of a solar power plant. Numerous countries have regulations regarding the sorts of land that can be used for solar projects. Generally, it is preferable to employ building land rather than agricultural land, as this would contravene the principle of sustainable growth.

**Geological disaster**

This is a critical geographical factor in the development of photovoltaic power plants. If an area is prone to geological disasters such as tsunamis and earthquakes, investors will face significant risks, and there is no value in installing solar farms in this area.

**Policy**

It is critical to consider local policies while selecting a location. Solar energy generation is expensive due to technical constraints. When a country or municipal government reduces taxes while increasing energy prices, investors are relieved and the investment rate increases.

**Social benefit**

The photovoltaic power station is built to meet the interests of investors while also contributing positively to society. It will assist in the promotion of local businesses, the creation of more jobs, and the impact on local education and culture\(^\text{29}\).

**Public attitude**
The development of a huge solar energy system is a massive and time-consuming endeavor. It frequently has a detrimental effect on nearby inhabitants, for example, noise. It is critical and appropriate to perform extensive research to ascertain whether the local populace supports solar energy generation.

**Local development planning**

It serves as the foundation for investment and commercial decision-making. If the local economy and social system have remained stagnant and saturated, the viability and hazards of investing in photovoltaic power stations must be evaluated.

**Payback period**

This is a critical factor to examine when determining if a project is worth investing in, and it is also a benchmark for decision makers when determining a project's profitability. When selecting a solar power plant, a project with a lengthy payback period is inappropriate and should not be prioritized.

**Investment cost**

Investment cost is a critical factor to consider while undertaking any project. It weighs the project's expenses and benefits. Consideration of this factor in the analysis of the optimal site of solar farms will result in a more cost-effective and dependable location outcome. The expenditure mostly encompasses the costs associated with land acquisition in this paper.

**Rainfall**

Rainwater may cause damage to photovoltaic (PV) and other construction equipment, reducing their useful life. Solar power plants should be constructed with extreme caution in places prone to excessive precipitation.

**Temperature**

Temperature can have an effect on the longevity of solar power generation devices. Increased temperature can reduce the efficiency of solar panel energy conversion devices, resulting in decreased output. When the average temperature is maintained at a steady and acceptable level, solar power plants can operate at maximum capacity.

**Humidity**

Increased humidity does result in less solar radiation, lowering the performance of photovoltaic energy and increasing the cost of power generation.

**Distance to roads/substations**
The technical strategy must account for the distance between solar farms and roadways and substations. Solar farms built near transformer substations will help reduce equipment transportation costs and enable the construction of new infrastructure.

**Population density**

This is an illustration of how metropolitan systems evolve. The distribution and number of populations are even more critical variables throughout the solar plant site selection process.

All of the factors stated above were determined with the assistance of experts and relevant institutions from around the world to bolster the viability of the site selection system and the data's dependability. Experts include local governments, government agencies, consultants, renewable energy specialists, project managers, quantity surveyors, engineers, architects, scientists, and developers. Their knowledge and abilities ensure the logic and dependability of the system.

### 3.2 The procedure for determining the optimal location for a solar power plant

This research evaluates the economic, environmental, geographical, and social factors of the study region, as well as the potential for solar energy growth, in order to maximize the site of a solar plant. Developed a more precise approach for determining the location of solar energy plants.

Figure 1 illustrates the process of choosing an alternate site for a solar farm. The specific steps are described as follows:

**Step 1**

Created a site selection model based on 16 factors and suggested some constraints to help define possible alternatives (S1, S2, S3).

**Step 2**

Collect and evaluate relevant data for each alternative in accordance with the site selection method. All collected data will be processed and used as input parameters for the CBA model.

**Step 3**

Determining the optimal site by using CBA methods.

This approach would improve the precision and objectivity of the site selection process's outcome. Notably, due to the low slope angle of the land in the study field, the slope and orientation of the land are not included in this research.

### 3.3 Study area and data collection
This study focused on the southern California counties of San Bernardino and Riverside (Fig. 2), which are mostly desert, sparsely populated, and bountiful in solar energy. As a result, the majority of California's solar projects are located in those two counties to supply electricity to western California's metropolitan clusters. To begin, the constraints indicated in Fig. 1 were used to select three suitable solar project locations (S1, S2, S3). Following that, specifics about possible places are provided. Prior to analyzing the alternatives, this study's data were collected and show in Table 2. All data and statistics are derived from a variety of sources, including the National Renewable Energy Laboratory (NREL), the Weather Atlas (WA) website, and the Bureau of Land Management (BLM).

### 3.4 CBA method

CBA's tabular approach is utilized to determine solar photovoltaic (PV) plant installation locations in this study. As illustrated in Fig. 3, the tabular CBA technique comprises of six steps.[33]

1. **Determine possible alternatives;** in this study, three possible alternatives (S1, S2, and S3) are ultimately produced by imposing some constraints on the investigation. These are the alternatives that are used to conduct the evaluation.

2. **Defining criteria and factors.** Section 2 discusses the criteria and elements that influence the location of solar energy plants. It's worth emphasizing that the majority of characteristics and variables are quantitative, which makes the CBA method's decision-making outputs more objective and reliable.

3. **Enumerating the characteristics of each alternative.** This process involves experts and stakeholders developing choice rules for each criterion and element, as well as summarizing the qualities of each alternative.

4. **Assessing advantages of each alternative.** This step requires stakeholders to evaluate the merits of each alternative based on specified characteristics and considerations, which should be a straightforward undertaking.

5. **Deciding the importance of each advantage.** Decision makers should prioritize each advantage. Participants used a scale ranging from 1 to 100 in order to assign varying degrees of importance. To begin, the "most critical benefit" should receive a score of 100. The following goal is to utilize the "most significant benefit" as a baseline against which to compare the remaining advantages. The final stage is to determine each alternative's Total Importance Advantages (IofAs).

6. **Choosing the best alternative.** Calculate the cost of each alternative scheme to obtain the cost - IofAs curve. The alternative that gives the most value for money should be chosen by stakeholders and decision makers.

### Result And Discussion

#### 4.1 CBA results
In contrast to the standard MCDM method, the CBA method places a premium on the relative advantages of factors rather than their relative importance. The goal of this study is to determine the suitability of a location for solar project construction using the CBA decision-making framework. To confirm the accuracy of the data and the method's viability, experts from around the world were enlisted to define criteria and weigh the relative merits of each choice. As a consequence, 15 decision-making elements and criteria (left column of Table 2) were found, with the exception of investment cost. Fig. 4 illustrates the score assigned by experts to each factor's advantage. Clearly, professionals prefer solar radiation potential, which has a maximum score of 100 and corresponds to a basic understanding of solar energy generation. Additionally, the overall score for technical and social variables is high, showing that decision makers place a premium on the benefits of these two factors when deciding on solar farm locations. Table 2 demonstrates how CBA can be used to organize data in a way that makes selecting the ideal solar plant location easier for experts and stakeholders.
### Table 2
CBA tabular method.

| Factors                   | Site | Attribute | Advantages                                                                 |
|---------------------------|------|-----------|-----------------------------------------------------------------------------|
| **1. Payback period**    | S1   | 18.75 year| It is the second shortest payback period.                                   |
| Criteria: The shorter the period, the better. | S2   | 18.71 year| It is the shortest payback period.                                          |
|                           | S3   | 19.51 year| -                                                                           |
| **2. Temperature**       | S1   | 33.40°C   | It is the most suitable temperature.                                        |
| Criteria: The lower temperature is, the better. | S2   | 34.00°C   | It is the more suitable temperature.                                        |
|                           | S3   | 40.70°C   | -                                                                           |
| **3. Visual impact**     | S1   | It is a desert valley with little flora. | Much better for solar project construction. |
| Criteria: The less vegetation or wildlife on the site, the better. | S2   | It is a place with a diverse vegetation. | - |
|                           | S3   | It is a valley with little tall vegetation | Much better for solar project construction. |
| **4. Rainfall**          | S1   | 10.20 mm  | -                                                                           |
| Criteria: The less the rainwater, the better. | S2   | 9.75 mm   | Less annual rainfall                                                       |
|                           | S3   | 6.10 mm   | Minimum annual rainfall                                                    |
| **5. Humidity**          | S1   | 39.60%    | -                                                                           |
| Criteria: The less the humidity, the better. | S2   | 37.80%    | The value is the second lowest of the three sites.                          |
|                           | S3   | 27.40%    | The value is the lowest of the three sites.                                |
| **6. Distance to substations** | S1   | 11.57 km  | The closer the location is to the substation, the easier it is to connect to the grid. |
| Criteria: The shorter the distance, the better. | S2   | 15.53 km  | It is close to the substation, which simplifies the process of connecting to the grid. |
|                           | S3   | 16.39 km  | -                                                                           |
| **7. Distance to roads** | S1   | 7.13 km   | The site is the closest to the road, significantly lowering the equipment's transportation costs. |
| Criteria: The shorter the distance, the better. | S2   | 12.46 km  | -                                                                           |
| Factors                                      | Site | Attribute     | Advantages                                                                                                                                                                                                 |
|----------------------------------------------|------|---------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| **8. Solar irradiation potential**           |      |               | **Criteria:** The higher the intensity of solar radiation, the better.                                                                                                                                 |
|                                              | S1   | 5.95 kW/m²/day| It possesses the world's most plentiful solar energy resources.                                                                                                                                              |
|                                              | S2   | 5.78 kW/m²/day| There is sufficient sun energy available to build a solar plant.                                                                                                                                              |
|                                              | S3   | 5.71 kW/m²/day| -                                                                                                                                                                                                         |
| **9. Land types**                            |      |               | **Criteria:** Deserts were favored, followed by valleys.                                                                                                                                                   |
|                                              | S1   | The area is classified as a high desert and is zoned for construction.                                                                                                                                       |
|                                              | S2   | The land is primarily used to build tourist amenities.                                                                                                                                                       |
|                                              | S3   | This area is primarily made up of building land and desert wasteland.                                                                                                                                          |
| **10. Geological disaster**                  |      |               | **Criteria:** Preferably no geological disasters.                                                                                                                                                             |
|                                              | S1   | There are no significant natural disasters or looming floods.                                                                                                                                                |
|                                              | S2   | There have been no significant natural catastrophes.                                                                                                                                                         |
|                                              | S3   | The location is located on a fault line, which means that mild earthquakes are possible.                                                                                                                      |
| **11. Policies**                             |      |               | **Criteria:** The more positive the impact on the construction of solar farms, the better.                                                                                                                    |
|                                              | S1   | There is little demand for electricity in this area.                                                                                                                                                          |
|                                              | S2   | This area's electricity is mostly used to support local tourism growth.                                                                                                                                      |
|                                              | S3   | In fact, this area will serve as a power transmission link between California and Arizona.                                                                                                                   |
| Factors                      | Site | Attribute                                                                 | Advantages                                                                 |
|-----------------------------|------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|
| 12. Social benefit          | S1   | Building the solar facility can boost economic development in the area.  | Promote local economic, social and cultural development. 70               |
|                             | S2   | Building the solar plant will help meet the tourism industry’s electricity needs. | Mainly promote local tourism. 65                                           |
|                             | S3   | Constructing a solar power plant can result in an increase in employment.  | -                                                                         |
| 13. Public attitude         | S1   | Most individuals are opposed to solar plant building.                     | -                                                                         |
|                             | S2   | The majority of people support the construction of solar power plants.    | It will significantly mitigate the impact of human variables. 35          |
|                             | S3   | Almost all of people advocate for constructing solar power facilities.   | It will eliminate all human-caused influences. 45                        |
| 14. Local development planning | S1   | Solar energy projects may not be included in the development plan.       | -                                                                         |
|                             | S2   | Solar energy projects are only a modest portion of the development plan.  | Promoting local development slightly. 65                                 |
|                             | S3   | Solar energy projects are a critical component of the development plan.  | Greatly promote the local development 75                                 |
| 15. Population density      | S1   | 640.96 km²                                                                | -                                                                         |
|                             | S2   | 198.15 km²                                                                | There is plenty of available land space. 40                               |
|                             | S3   | 285.87 km²                                                                | There is a small amount of available land space. 30                      |
| Cost (Million dollar)       | S1: 3.96 | S2: 3.82                                                                     | S3: 2.98                                                                  |
Factors | Site | Attribute | Advantages
---|---|---|---
Total IofAs divided by 100: | S1: 4.43 | S2: 6.17 | S3: 4.00

To facilitate analysis of the results, the IofAs (Importance of Advantages) values in this study were divided by 100. Fig. 5 illustrates a cost analysis of each alternative in terms of IofAs. S2 had the second lowest cost and the highest IofAs value when compared to S1 and S3. S1 and S3 have similar IofAs values, however S3 is substantially less expensive. In conclusion, S2 is the optimal location for solar plant construction using the CBA technique due to its higher cost performance, and the final ranking is S2>S3>S1.

### 4.2 Comparative analysis of conventional MCDM method and CBA

To validate the CBA results, this study used the TOPSIS and PROMETHEE comparative analysis methodologies. There are two primary reasons for selecting these two methods. The first is that they are the most often utilized methods for solar farm site selection, making them highly representative. Second, the decision-making philosophy of these two systems is diametrically opposed to that of the CBA method, implying a sharp comparison. The ranking of solar farm site selection alternatives based on standard MCDM and CBA approaches is shown in Table 3. S2=0.488> S1=0.564> S3=0.473 while using TOPSIS, however S2=0.045 > S1=0.029 > S3=-0.073 when using PROMETHEE. The rankings produced by these two approaches are identical. This demonstrates that the classic MCDM method has the same decision performance. Clearly, this result is not the same as the one reached using the CBA technique (S2>S3>S1). The fundamental reason for this is that the investment cost was factored into the TOPSIS and PROMETHEE method evaluations at the beginning, and as a result, potential site S3 is scored better than S1 due to its superior social and environmental performance. In other words, the disadvantage of S3's investment cost is outweighed by its other benefits. As a result, when traditional MCDM methods are used to make a choice, the investment cost is weighed against other criteria. Unlike the typical MCDM technique, the CBA model incorporates the predicted investment cost of each choice as an independent parameter. That is, despite the fact that S1 performed brilliantly in this study and achieved a high score in a multitude of areas, Due to the high estimated investment cost, investors and decision makers would continue to shun it.
To emphasize this property of CBA, the cost of the three site selection possibilities is maintained constant for analysis in this study. Tables 4 and 5 detail the findings when the total cost of all alternatives is set to the maximum and minimum values, respectively. Clearly, the CBA approach and the classic MCDM method provide the same outcomes when all participating options have the same investment cost. However, in practice, the location of solar farms will be influenced by a variety of factors, and the investment costs of different projects will vary significantly as a result of the influence of various surroundings and legislation. As a result, the CBA technique outperforms the classic MCDM method when it comes to making decisions about projects with significant cost discrepancies.
Table 5  
The three approaches’ final ranking (when all costs are the minimum cost of the alternative).

| Alternatives | Conventional MCDM methods | CBA method |
|--------------|---------------------------|------------|
|              | TOPSIS                    | PROMETHEE  |
|              | Closeness coefficients   | Ranking    | Net outranking flow | Ranking | IofAs | Cost (Million dollar) | Ranking |
| S1           | 0.489                     | 2          | 0.047               | 2       | 4.23  | 2.98                  | 2       |
| S2           | 0.566                     | 1          | 0.033               | 1       | 6.42  | 2.98                  | 1       |
| S3           | 0.474                     | 3          | -0.065              | 3       | 3.90  | 2.98                  | 3       |

Additionally, in comparison to the traditional MCDM method, decision makers can use CBA to make decisions based on their own needs in response to cost changes. Table 6 and Fig. 6 illustrate the decision-making outcome when the costs in S1 vary proportionately.

Table 6  
When the costs in S1 change, the final outcome of the CBA method.

| Proportion | Cost of S1 (Million dollar) | Ranking result |
|------------|-----------------------------|----------------|
|            |                             | S1  | S2  | S3  |
| -20%       | 3.208                       | 2   | 1   | 3   |
| -10%       | 3.564                       | 3   | 1   | 2   |
| 0%         | 3.960                       | 3   | 1   | 2   |
| 10%        | 4.356                       | 3   | 1   | 2   |
| 20%        | 4.572                       | 3   | 1   | 2   |

Clearly, as the cost of S1 is reduced, its cost performance improves. When the cost of S1 is lowered by approximately 20%, the cost performance index (the value of IofAs divided by the cost) of S1 is greater than the cost performance index of S3. This signifies that S1 outperforms S3 in terms of cost performance, and the findings of the CBA method will be changed to S2>S1>S3. As can be seen, CBA facilitates more transparent and adaptable decision-making.

In conclusion, while all three approaches are designed to help decision makers analyze their preferences, the CBA method gives a more complete cost analysis and a simpler process. When considering considerations, the CBA requires decision makers to assess the relative value of each benefit in the
context in which it is being considered. By contrast, the standard MCDM method places a premium on the significance of components when evaluating projects.

4.3 Sensitivity analysis

To ensure the stability of CBA results, two scenarios are designed to investigate how the results fluctuate when one aspect's advantages change. In our situation, we altered the relative advantages of technology and social elements. This is because technical and social factors are weighted greater than other factors. In other words, the advantages of these two factors outweigh the disadvantages of the others. These two scenarios are detailed in Table 7.

Scenarios A: Modify the benefits of parameters connected to the social component proportionately while maintaining the benefits of other factors.

(a) Decrease the IofAs of social factors by 20% while maintaining the IofAs of other factors.
(b) Decrease the IofAs of social factors by 10% while maintaining the IofAs of other factors.
(c) All IofAs remain unchanged.
(d) Increase the IofAs of social variables by 10% while maintaining the IofAs of other factors at their current level.
(e) Increase the IofAs of social variables by 20% while maintaining the IofAs of other factors at their current level.

Scenarios B: Modify the advantages associated with the technology aspect proportionately while maintaining the advantages associated with the other factors.

(a) Decrease the IofAs of technological factors by 20% while maintaining the IofAs of other factors at its current level.
(b) Decrease the IofAs of technological factors by 10% while maintaining the IofAs of other factors.
(c) All benefits remain unchanged.
(d) Increase the technological IofAs by 10% while maintaining the advantage of other factors.
(e) Increase the technological IofAs by 20% while maintaining the advantage of other factors.

The IofAs and I/C (IofAs divided by Cost) values for each alternative in various situations are shown in Tables 7 and 8. The resulting rankings for these two scenarios are displayed in Figures 7 and 8, which are in comparison to the baseline scenarios depicted in Fig. 5. Clearly, the ranking of I/C values remains constant across all circumstances. This demonstrates the robustness of CBA's ranking result, as slight changes in the advantage assignment do not affect the ranking.
Table 7
The values of IofAs in different scenarios.

| Scenarios A | (a)  | (b)  | (c)  | (d)  | (e)  |
|-------------|------|------|------|------|------|
|             | -20% | -10% | 0%   | +10% | +20% |
| S1(IofAs)   | 4.290| 4.360| 4.430| 4.500| 4.570|
| S2(IofAs)   | 5.620| 5.895| 6.170| 6.445| 6.720|
| S3(IofAs)   | 3.530| 3.765| 4.000| 4.235| 4.470|

Scenarios B

| S1(IofAs)   | 4.290| 4.360| 4.430| 4.500| 4.570|
| S2(IofAs)   | 5.620| 5.895| 6.170| 6.445| 6.720|
| S3(IofAs)   | 3.530| 3.765| 4.000| 4.235| 4.470|

Table 8
The values of I/C and the final ranking results in different scenarios.

| Scenarios A: | Rank | | | | |
|--------------|------|------|------|------|------|
|              |      | (a)  | (b)  | (c)  | (d)  | (e)  | (a)  | (b)  | (c)  | (d)  | (e)  |
|              |      | -20% | -10% | 0%   | +10% | +20% | (a)  | (b)  | (c)  | (d)  | (e)  |
| S1(I/C)      |      | 1.083| 1.101| 1.119| 1.136| 1.154| S1   | 3    | 3    | 3    | 3    |
| S2(I/C)      |      | 1.886| 1.978| 2.070| 2.163| 2.255| S2   | 1    | 1    | 1    | 1    |
| S3(I/C)      |      | 1.252| 1.335| 1.418| 1.502| 1.585| S3   | 2    | 2    | 2    | 2    |

Scenarios B:

| S1(I/C)      |      | 1.013| 1.066| 1.119| 1.172| 1.225| S1   | 3    | 3    | 3    | 3    |
| S2(I/C)      |      | 1.980| 2.025| 2.070| 2.116| 2.161| S2   | 1    | 1    | 1    | 1    |
| S3(I/C)      |      | 1.397| 1.408| 1.418| 1.429| 1.444| S3   | 2    | 2    | 2    | 2    |

Conclusions

This paper begins by discussing the development of solar energy in California, the United States of America, and points out that with the expansion of solar energy projects, location selection for solar
power farms will become more difficult. As a result, this paper will examine solar farm site in order to give technical support for solar energy projects in California.

Additionally, this study discusses the process of solar energy plant site selection. The conclusion is then drawn that the typical MCDM approach is incapable of handling the site selection difficulties associated with solar energy production. As a result, it is important to develop a new way of thinking and acting in order to meet the needs for new energy deployment.

In this vein, this research created a more precise and detailed method for large solar plant site selection that takes into account economic, technological, social, geographic, and environmental elements, as well as a number of factors based on essential criteria. According to the decision-making outcomes, a region's solar project potential is clearly determined by its high prospective solar radiation, policies, and investment prices. Then, utilizing CBA, an optimum strategy for solar plant site selection in southern California, USA, was presented. To begin, limits on the selection of three possible choices are placed. After that, the CBA model was utilized to classify those potential locations. The CBA findings indicate that S2 is the optimal location for solar plant construction.

To demonstrate CBA's advantages, the standard approaches TOPSIS and PROMETHEE are compared to CBA. The results indicate that when the costs of all alternatives are very variable, CBA can provide a more accurate and flexible cost analysis. As a result, the solar industry's adoption of CBA enables the decision-making team to make an accurate assessment of the project's importance and risk tolerance. Cost analysis enables the project's management team to make more informed and smart choices.

Declarations

Data availability

The data used in the publication were made from meteorology and geography. It is widely mentioned in the “Methodology” section of the article.

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Author contributions

H.H.G. Overall investigation, writing – review & editing. C.L. Data collection and writing – original draft. D.Z. and W.D. Formal analysis. C.S.L. Data analysis. T.A.K. Validation. K.C.G. Editing.

Competing interests

The authors declare no competing interests.
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**Figures**

![Solar plant location selection framework](image)

**Figure 1**

Solar plant location selection framework.
Figure 2

Map of the study area.
1. Determine possible alternatives

2. Defining criteria and factors

3. Enumerating the characteristics of each alternative

4. Assessing advantages of each alternative

5. Deciding the importance of each advantage

6. Choosing the best alternative

**Figure 3**

CBA Steps

**Figure 4**

The score distribution of each factor’s advantage.
Figure 5

the ranking result of CBA method.
Figure 6

The final result of CBA method when the costs in S1 change.
Figure 7

Result analysis based on scenario A.

Figure 8

Result analysis based on scenario B.