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CHOOSING BY ADVANTAGES (CBA) TO SELECT THE BEST LOCATION FOR A SOLAR PHOTOVOLTAIC PLANT IN THE PRE-FEASIBILITY STAGE

Kevin Aza[1], Andrews A. Erazo-Rondinel [2], Lao J. Li-Albrizzio [3], Mauricio A. Melgar[4], and Anthony F. Paucar-Espinoza [5]

ABSTRACT

The energy transition from fossil fuels to pollution-free and sustainable energy has been a common goal for all countries worldwide. In line with this transition, the Peruvian industry and many others worldwide seek to develop new renewable energy projects. Solar photovoltaic energy is the preferred option due to the significant potential in its territory. This research aims to show the application of the CBA methodology in selecting the best location for a solar Photovoltaic (PV) plant to develop a pre-feasibility study whose area of interest are the Peruvian Andes. The analysis was based on identifying the advantages of each factor considered in evaluating the best sites for the location of a solar PV plant. The results showed that the CBA methodology is very important when performing pre-feasibility studies for solar PV plants, where costs do not make substantial differences between alternatives. This research will be a valuable tool for the community of professionals in developing renewable energy when performing pre-feasibility studies in which there needs to be more information on the area of interest. The aim is to define the location with the best solar photovoltaic potential.

KEYWORDS

Choosing By Advantages, Solar PV Plant, ubication, Lean Construction, Sustainability, decision-making.

INTRODUCTION

Energy consumption by the world's population has increased exponentially in recent years, so the search for new energy sources, preferably renewable and non-polluting, has become necessary. Solar energy has been approaching as a solid response to the problem and has gained ground in the main first-world countries, spreading over the years to developing countries (García de Fonseca et al., 2019). However, constructing facilities for energy generation using solar panels, which capture sunlight and convert it into energy, has required rigor and demand

[1] Researcher, Faculty of Civil Engineering, Universidad Nacional de Ingeniería, Lima, Peru, kazav@uni.pe, orcid.org/0000-0003-2714-6889

[2] Teaching Assistant, Professional School of Civil Engineering, Universidad Continental, Huancayo, Peru, aerazo@continental.edu.pe, orcid.org/0000-0002-5639-573X

[3] Student Researcher, Faculty of Civil Engineering, Universidad Nacional de Ingeniería, Lima, Peru, lao.li.a@uni.pe, orcid.org/0000-0001-9937-7411

[4] Student Researcher, Faculty of Civil Engineering, Universidad Nacional de Ingeniería, Lima, Peru, mauricio.melgar.m@uni.pe, orcid.org/0009-0007-6491-4134

[5] Researcher, Faculty of Civil Engineering, Universidad Nacional de Ingeniería, Lima, Peru, apaucare@uni.pe, orcid.org/0000-0002-5369-1584

for the correct energy supply to society. Determining the best construction location for the solar plant is one of the critical points when seeking to generate energy (Aly, 2017) since it influences the technology of solar panels, the amount of energy produced, ease of construction, and economic costs, among others.

That is why different researchers have applied mathematical methods to select the location of a solar plant. Wang et al. (2018) proposed using a Multi-criteria Decision-making model (MDCM) that combined three methodologies, including Data Envelopment Analysis (DEA), Fuzzy Analytical Hierarchy Process (FAHP), and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). On the other hand, Sánchez-Lozano (2013) proposed combining the Geographic Information System (GIS) and MDCM methods such as AHP and TOPSIS. The aforementioned mathematical methodologies are the ones that are mainly used in research on the selection of the location of solar plants.

Although these applied mathematical methods help us decide, they do not adapt to different cases or extract the project context (Martínez et al., 2016). One method adapted to the projects and the context is Choosing By Advantages (CBA), a decision-making system developed by Suhr (1999), whose importance lies in the advantage of the factors rather than the factors themselves. CBA has applications in different topics, including those related to sustainability.

Goh et al. (2022) apply CBA for the selection of the location of a solar plant in Southern California, USA, during the feasibility stage. This application of CBA is focused on a reality that has different characteristics, first at the level of development phases (the information available at a feasibility stage is very different from that of a pre-feasibility stage), and then at the country level, considering the deficiencies in Peruvian regulations regarding the promotion of renewable energies. (Gamio et al., 2017). The study of the quantification and tabulation of meteorological data from stations between 1975 and 1990 (Tamayo, 2011) determined that compared to other countries, Peru has solar energy availability in almost all of its territory, being large and uniform throughout the year (SENAHMI, 2003).

Therefore, the following research aims to implement CBA for the selection of the location of a solar plant in Peru in the pre-feasibility stage. To this end, a literature review on the decision-making methods in solar plants is carried out, followed by the implementation of CBA. Then the results are discussed to evaluate whether the factors change by geographical location and project development stage.

BACKGROUND

In this section, the authors will initially discuss Choosing by Advantages (CBA) due to its relevance to understanding the difficulties in determining a construction site for a photovoltaic solar plant.

Decision Making in Solar Plants

The appropriate location of a solar PV plant is the most critical decision in project design and subsequent construction (He-Yau & You-Jyun, 2017). Thus, some authors have developed different decision-making methods to solve this problem. One example is El-Azab & Amin (2015), who proposed an algorithm to optimize the selection of locations to build a solar plant in North Africa and the Middle East and applied it to a case study in Egypt. The algorithm defined the average global solar radiation for each day, calculated the transmission losses, and calculated the average energy generated in a year. Finally, the net transmitted energy of all alternatives was compared to choose the option that generates the most energy in a year.

Thongpun et al. (2017) used the DEA method to select the location of a solar plant in Thailand based on the efficiencies of plant sites in 77 provinces in Thailand. Factors affecting the efficiency of solar panel systems, energy output power, and solar plant area selection were considered: resource availability, economic impact, environmental concern, social concern, and accessibility. Once the study was completed, efficiency percentages were obtained for a linear and non-linear DEA model.

Rezaei et al. (2017) investigated seven regions in the Iranian province of Fars to assess the best location for constructing a wind-solar hybrid power plant. Wind and solar potential were considered the most critical factors. This information was obtained using the Weibull distribution function and the Angstrom-Prescott equation in the Meteorological Organisation of Iran database from 2006 to 2015. The method consisted of using fuzzy TOPSIS for data analysis and ranking, then MCDM methods (AHP, DEA) were used to verify the results obtained.

Lee, Kang, and Liou (2017) propose a multi-criteria decision-making model to choose the best construction site for a photovoltaic solar plant in Taiwan. The model consists of using interpretive structural modeling (ISM) to determine the interrelationship between criteria and sub-criteria, then using fuzzy analytic network process (FANP) to obtain the weights of the sub-criteria, and finally, multi-criteria optimization and compromise solution (VIKOR in Serbian) to rank the photovoltaic solar plant locations. After the application, it was obtained that the most important criteria were costs and physical environment. At the same time, the most critical sub-criteria were land utilization, land cost, repair and maintenance cost, and soil quality.

Rediske et al. (2020) proposed a model for the location of photovoltaic power plants in the central region of Rio Grande do Sul - Brazil. The model consists first of an area analysis with the gvSIG software, using the AHP method to give weight to each factor, and finally using TOPSIS for the order of alternatives. An area of 1823.35 km2 was studied, determining that 19.91% was excellent for the location of a solar plant. They considered the most critical factors of the environmental type, location, climate, geomorphological, Substation Distance, and Solar Irradiation.

CHOOSING BY ADVANTAGES & SUSTAINABILITY

CBA is a multi-criteria decision-making system based on the importance of "advantages" between alternatives (Suhr, 1999), which includes principles and definitions, where models, methods, tools, and techniques are also concentrated. The CBA system includes methods for virtually all decisions, from the very simple to the very complex. Among all these methods, Arroyo (2015) indicates that the most used is the Tabular CBA Method. In the construction industry, there are many applications where this method can be used; mainly, it has been applied in different sustainable decisions, showing many benefits, for example:

Arroyo et al. (2013) applied this method to improve decision-making in selecting ceiling tiles, showing benefits such as identifying relevant sustainability factors, providing documentation for rational decision-making, and identifying relevant advantages to make transparent, transparent, and conflict-free exchanges between options. Also, Arroyo et al. (2015), in a commercial interior design project, chose a sustainability alternative for roof tile materials; the study contributed to knowledge by integrating stakeholder perspectives considering sustainability factors, identifying sustainability factors according to context, and how to discriminate IofAs, among others.

Arroyo et al. (2016) compared CBA and Weighting Rating and Calculating (WRC) in groups of professionals to make decisions involving sustainability factors in architecture, engineering, and the construction industry.

Torres-Machi et al. (2019) evaluated the sustainability of pavement management decisions. AHP and CBA are used in a case study comparing pavement maintenance technologies using cold-in-place recycling and traditional solutions based on mill and overlay.

Perez and Arroyo (2019) used CBA and Design Structure Matrix (DSM) to redesign the waste collection program. CBA was used for three complex decisions and supplemented with DSM to decrease negative iterations by finding the proper order of decisions. By applying CBA, sustainability solutions are achieved, and by applying DSM, it was possible to solve the problem of being able to consider decisions.

Milion et al. (2021) used CBA to classify the impact of defects in residential buildings and improve sustainable managerial decisions where risk can affect the quality of projects from the customer's perspective.

Finally, Goh et al. (2022) apply CBA for the selection of the location of a solar plant in Southern California, USA, during the feasibility stage. Through an exhaustive literature review, Goh et al. (2022) identified the different factors in their decision-making. The factors that obtained a higher score for decision-making are in the following order: solar irradiation potential, policies, and payback period.

RESEARCH METHODOLOGY

CASE STUDY

The case study is selected due to the importance of solar PV energy in the energy development strategy (Goh et al., 2022). The case study consists of a project for a Potential Study (typical of a pre-feasibility stage) for the conception and development of a solar PV plant in the Andean region of Peru. Therefore, the two most relevant aspects for the project owner were: the location of the asset (close to important cities in the Andean region of Peru) and the capacity and energy yield of the solar PV plant. However, due to the experience and knowledge of the professionals involved in the project (technical staff), additional criteria were established for developing an asset of this type. Therefore, the area of interest had to be studied for different location options.

Thus, four alternatives with appropriate characteristics and conditions for a solar PV project are proposed, from which the best one has to be chosen. For this reason, it is necessary to consider a methodology that enables one to decide based mainly on value, which will be discussed in more detail in the following sections.

CHOOSING BY ADVANTAGES

For the CBA application to determine an optimal construction site for a photovoltaic solar plant, the decision involved the participation of an electrical specialist, a geographic information specialist, a hydrological specialist, a geotechnical specialist, and a renewable energy specialist. Due to the fundamental role of the participation of the professionals involved in the project in defining the context of the decision (Martinez et al., 2016), the CBA Tabular Method allows for capturing the perspectives of decision-makers with different opinions. The steps involved in applying the CBA Tabular Method are detailed in the seven steps indicated in Figure 1:

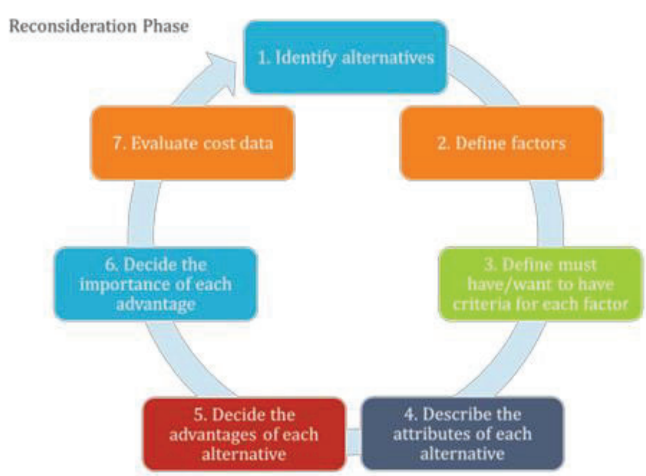

Figure 1: CBA Tabular Method steps (Arroyo, 2022)

The application of the steps of the CBA Tabular Method in the case study will be explained below:

Step 01: Identify the alternatives

A preliminary analysis is made in an area near major cities in the Andean region of Peru. Next, a suitable construction site is sought for the location of a photovoltaic solar plant. In this step, the project team identified four zones as alternatives (Table 1).

Table 1: Alternatives of Case Study

Alternatives	Description of the alternative
Alternative 1	Location A in the central Peruvian Andes, of approximately 888 hectares.
Alternative 2	Location B in the central Peruvian Andes, of approximately 1375 hectares.
Alternative 3	Location C in the central Peruvian Andes, of approximately 694 hectares..
Alternative 4	Location D in the central Peruvian Andes, of approximately 975 hectares.

Step 02: Define the factors

The project team needs to identify factors that support discerning the best alternative among those listed. Following the review of relevant literature and consulting with industry experts, six essential factors for site selection are suggested as follows in Table 2:

Table 2: Factors of Case Study

Factor	Unit of measurement	Description of the factor
The slope of the land	The measure of slope [%]	It is essential to know the slope of the land when the owner wants to build a solar PV plant on the site because the lower the slope, the shading effect will be. The slope also affects how it will be built (whether it will require additional work) or whether the land is appropriate for construction.
Distance to the connection point	The measure of distance in Kilometer [km]	The distance to the connection point (electrical substation or transmission line) where the energy will be directed must be considered when designing the solar PV plant. The longer the distance, the higher the transmission losses.
Availability of area for future expansions	The measure of surface area in Hectare [Ha]	The project owner has expressed his long-term interest in further developing photovoltaic generation in the country. Thus, this project would be a first step in its strategy and seek to expand the solar PV plant in the coming years.
Condition of access routes	-	The condition of the main access roads to the alternatives is important to make the most efficient choice. Poor road conditions can cause problems during the construction of the solar PV plant.

Power generation	Amount of energy generated (kWh) per installed capacity (kWp) (Specific energy production) [kWh/kWp]	Solar power generation is a crucial factor, as this influences the capacity and energy yield of the future solar PV plant.
Presence of protected ecosystems	-	The presence of protected or endangered flora or fauna within or near the solar PV plant in a country as biodiverse as Peru implies elaborating a detailed environmental management plan, a series of inconveniences with land use permits, or even the impossibility of using the site for a photovoltaic generation.

Step 03: Define the criteria for each factor

The criteria to select the best alternative among the four available are based on the degree of impact on the project's viability. These have been based mainly on the Preliminary Selection Criteria, the analysis criteria of the field visit, and the estimated generation in the Preliminary Evaluation of Photovoltaic Energy Production (shown in Table 3).

Step 04: Describe the attributes of each alternative

The information collected from the four alternatives is used to obtain the attributes according to the factors and their criteria mentioned in the previous steps. The least preferred attribute is underlined and will serve as a point of comparison to describe the advantages (shown in Table 3).

Step 05: Decide the advantages of each alternative

Criteria are applied to identify advantages. In this case, the team first identified the least preferred attribute, highlighted it, and then used it as a basis for the comparison with the other attributes in each factor. Then, differences are defined as the advantages of the alternatives. The most significant advantage for each factor is shown in red and italics in Table 3.

Step 06: Decide the importance of each advantage

This part of the process is collaborative, and decisions are reached through discussion within the project team and the technical staff. A factor listed the most preferred advantages, and they are given an order of priority to define which are the most relevant when choosing an alternative.

Subsequently, a ranking is generated with weighting where the IoA (Importance of Advantage) is defined as the supreme advantage (a most important advantage when the decision is made) with a value of 100. Then, the IoAs of the other most preferred advantages is defined, always having as reference the value of the supreme advantage. Finally, with the IoAs for the most preferred advantages already defined, the IoAs for the other advantages were calculated proportionally (shown in Table 3).

Table 3: Evaluation using CBA Tabular Method

Factor (Criterion)		Alternative 1		Alternative 2		Alternative 3		Alternative 4	
Land Slope	Att.:	**3% - 5%**		**5%-10%**		**5%-10%**		**3%-5%**	
(The less, the better it is)	Adv.:	It has less slope	Imp 40		Imp		Imp	It has less slope	Imp 40
Distance to connection point	Att.:	35 Km		**11 Km**		29 Km		**47 Km**	
(The closer, the better it is)	Adv.:	12 Km closer	Imp 20	36 Km closer	Imp 60	18 Km closer	Imp 30		Imp
Area availability	Att.:	888 Ha		**1375 Ha**		**694 Ha**		975 Ha	
(The more available, the better)	Adv.:	194 additional Ha	Imp 3	661 additional Ha	Imp 10		Imp	281 additional Ha	Imp 4
Condition of access roads	Att.:	Medium		**Bad**		Medium		**Good**	
(The better condition, the better it is)	Adv.:	Better condition	Imp 20		Imp	Better condition	Imp 20	Much better condition	Imp 30
Energy generation	Att.:	**2121.7 kWh/kWp**		2174.9 kWh/kWp		2252.1 kWh/kWp		**2313.7 kWh/kWp**	
(The more it generates, the better it is)	Adv.:		Imp	53.2 kWh/kWp more	Imp 28	130.4 kWh/kWp more	Imp 54	192 kWh/kWp more	Imp 100
Presence of protected ecosystems	Att.:	**Not found**		**Yes**		**Not found**		**Not found**	
(The less presence, the better it is)	Adv.:	Less presence	Imp 50		Imp	Less presence	Imp 50	Less presence	Imp 50
Total IoA		133		98		154		224	

Step 07: Evaluate cost data

In this step, the project team did not evaluate costs because this research is related to the pre-feasibility stage of a project to construct a photovoltaic solar plant. At this project stage, costs do not generate differences between alternatives, so selecting the best alternative was based only on value.

DISCUSSION

In order to select the 4 study alternatives, an exhaustive search had to be carried out in the area of interest so that, based on the established factors and criteria, four sites with attractive attributes could be determined for further study.

Thus, the application of the CBA Tabular Method for the selection of the best alternative for the location of the solar PV plant has proved to be convenient, as it has taken into account factors typical of a pre-feasibility study that can lead the way for the large-scale development of solar PV projects and, why not, also of renewable energy projects in general in Peru.

In this way, it was possible to define the advantages of each factor considered, which is classified by the technical staff who adopted the methodology with great enthusiasm. In Peru, value is only sometimes prioritized in engineering and construction projects. Therefore, some benefits gained were training staff in CBA and identifying the value of each alternative in an engineering project. Meanwhile, barriers to implementing the CBA method were the initial unwillingness of top management to leave conventional methods behind and the time for staff training in CBA.

During this discussion, it was determined that energy generation was a preponderant factor in the project's conception. It will be the source of income that will make the project viable throughout its useful life and is closely linked to the other factors. The other factors were also considered relevant in the analysis, but taking into account that, for example, there are projects by the Peruvian State for the improvement and expansion of the National Interconnected Electricity System and the National Road Network; these will eventually have a lower preponderance than energy generation.

Compared to Goh et al. (2022), who conducted similar research where they applied CBA for the location of solar panels in Southern California in San Bernardino and Riverside counties, the research has shared certain factors.On the one hand, while in the present investigation, the factor of "power generation" has been taken into account, Goh et al. (2022) considered the "solar irradiation potential" factor, both alluding to the fact that it is important to consider the amount of energy that would be produced due to the position of the solar plant that would allow it to capture the most significant amount of sunlight.

Another couple of factors that are also similar between the present investigation and the investigation in California are, respectively, "Condition of access routes" and "Distance to roads/substations." Both factors refer to the fact that it would be more appropriate to select a place with easy access to reduce as much as possible the costs of transporting materials or equipment and to facilitate the construction of the plant. Regardless of the context of the work, the factors mentioned above will likely be considered when deciding the location of the solar plant due to its high impact on value generation. However, other factors may or may not become part of the analysis, depending on the context of the decision that comes to be considered when applying the CBA (Martinez et al., 2016).

Goh et al. (2022) mentioned that sixteen factors were obtained to apply the CBA, which were obtained due to the assistance of experts and important institutions worldwide. For that reason, special consideration was not taken to the context of the place. On the other hand, the present investigation considered only six factors that are focused on the context of the project. For this reason, there is a big difference between the factors used in both investigations. For example, we have the factor "availability of area for future expansions," which is essential in selecting this research because the project owner has shown great interest in expanding the photovoltaic solar plant. Another example would be the factor "presence of protected ecosystems," which has a high preponderance in the study area due to the high biodiversity in the flora and fauna of Peru. Likewise, the main factor was power generation, which has also been considered by similar investigations that applied other MCDM methods, such as Rediske et al. (2020), Rezaei et al. (2017), Sánchez-Lozano (2013), among others.The factors that are most often repeated in this type of research are "solar irradiation," "distance to roads," and "distance to substations." In addition, in some studies, the "slope" and "distance to power lines" are considered, as in the present investigation, and others, the "agrological capacity" is considered instead.

However, the main difference between Goh et al. (2022) and the present paper is the information required for the analysis. While Goh et al. (2022) propose an analysis with 16 criteria, in which data from a feasibility study are framed, where the technical characteristics of the location are known, in this paper, we intend to establish the analysis based on identifying the potential of different locations within an area of interest, considering that the information that may be at hand (such as geology, connection conditions, among others) is minimal or non-existent. Basic design criteria will be considered for this selection.

CONCLUSIONS

The application of the CBA Tabular Method enabled selection of the best location for a solar PV plant in the pre-feasibility stage, considering the Andean region of Peru as the area of interest. As part of this analysis, it was determined that Alternative 4 is the best located for the rest, standing out mainly for its energy generation and its low slope. Other factors in its favor are the good condition of its accesses and the absence of protected ecosystems within or near the alternative. As factors in which it does not have an absolute advantage over the rest, we can mention a smaller area available for expansion (compared to Alternative 2) and the distance to the connection point. These factors should be re-evaluated later (during feasibility) to determine whether they can improve their contribution to the value of the project.

This study aims to contribute to developing renewable energy projects at a preliminary stage (pre-feasibility), mainly in Peru, which has one of the world's most considerable solar PV potentials (Gamio, 2017). It also seeks to promote the use and study of the CBA decision-making system in various industry and engineering sectors, applying it in this case to a project closely linked to sustainability, climate change, and energy transition.

The results obtained indicate that the application of the CBA Tabular Method helps to select the best alternative for the location of a solar PV plant based on the value it provides, considering that in the development of pre-feasibility studies, the costs are referential and do not mark essential differences between the alternatives.

Likewise, the authors suggest implementing other lean principles in solar plants: process management in the evaluation of photovoltaic solar assets (value stream mapping), implementation of the last planner system in the construction of photovoltaic solar plants, application of lean project delivery system in the development of photovoltaic solar projects and others. Specifically, as the next steps for extending this research, further research on selecting equipment (technology) in solar photovoltaic plants and applying Choosing By Advantages decision-making system should be performed.

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