Applying Pareto meta-analysis in location selection for photovoltaic plant

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Abstract

In decision-making situations, it is common to have a set of alternatives and to choose the best among them or to establish a ranking. Multi-criteria decision methods can be applied to obtain different rankings, even though the set of alternatives and criteria are the same. Considering this, the idea of Pareto analysis is discussed to process the results obtained by different methods and reach a consensus. Those alternatives that are non-dominated will be considered the best set. That reduces the number of alternatives to be chosen because only the best set of alternatives should be taking into account.

Keywords: multi-criteria decision methods, ranking, Pareto analysis.

1. Introduction

In the late XIX century it was detected natural changes in the climatic conditions of the Planet Earth and it was identified for the first time the greenhouse effect [1], as a result, the international scientific community alerted the public about the negative effects that this discovery could lead.

However, it was not until a century later when, through the World Meteorological Organization (WMO) AND United Nations Environment Program (UNEP), the Intergovernmental Panel Climate Change (IPCC) elaborated a report in which it was indicated the veracity of global warming and at the same time it was requested the international community action in order to avoid it [2-4].

That is why international and national energy policies [5-9] had been adopted, which allowed boosting the development of renewable energy facilities.

Southeastern Spain, specifically the region of Murcia, has one of the highest levels of solar radiation potential in the country. The average annual global radiation in most of its territory overcomes the 5.00 kW/m2 by day. Therefore, it seems a reasonable bet to boost on solar photovoltaic energy in the territory. However, it is not uncommon that choosing solar photovoltaic plant locations involves a degree of uncertainty that may be avoidable in most cases. Generally, this could be avoided. Optimal location of these facilities involves a large number of criteria with different intensity in the process of decision making. Thus, to solve these specific location problems, it is useful to use multi-criteria decision methods (MCDM).

To the aim of the present paper, 8 parcels were selected as the alternatives to be evaluated. They are located in the municipality of *San Pedro de Pinatar*, in the coastal region of Murcia. The objective of the paper is to study and analyze the use of Pareto front when various multi-criteria decision methods are applied with the different rankings obtained. To do this, the paper will be divided into four main sections: first, a description of the multi-criteria decision-making methods to be used throughout the work; second, a brief review of multi-criteria decision method applications; third, a description of the Pareto analysis; fourth, the study of the most suitable parcels where solar photovoltaic plants can be installed, by applying multi-criteria decision methods and Pareto analysis. Finally, the main conclusions reached through the paper will be outlined.

2. Multi-criteria Decision Making

The decision making area has experimented a fast growth in the last years. This area contained a set of techniques and methods. In general terms, a decision problem is a situation where an individual has alternative courses of possible actions, and she/he has to select one of them without a previous knowledge of which one is the best [10]. In addition, the complex current organizations, do not try to maximize or minimize a determined utility function. Instead of that, different objectives come into question at the same time; most of which are incompatible among them. Finally, what they want is to obtain a determined level in each objective.

Therefore, the objective of the decision process is generating effective solutions from the available data, supplying a good understanding of the structure of the decision problem. These decision problems involve six components:

- The objective or objectives, that the decision maker or the institution wishes to fit
- The set of criteria
- The set of decision alternatives
- The relative importance and interconnection of the criteria
- The set of outcomes or consequences associated with each pair of alternatives /criteria

- The decision-maker or group of decision-makers involved in the decision making process with their preferences

In this case, an important question is which alternative could be choosen when multiple alternatives from multiple criteria are evaluated. In order to solve this question, MCDM were created [11]. By applying multi-criteria analysis, a global value for each alternative can be obtained. This value is composed of the values (V_{ij}) of the alternatives (A_i) with respect to each criterion (C_j), and of the weights (W_j) of the criteria (Figure. 1). The alternatives are finally ranked according to global values. In general, the alternative with the highest value should be selected as the best one. Nevertheless, it depends on the type of problem.

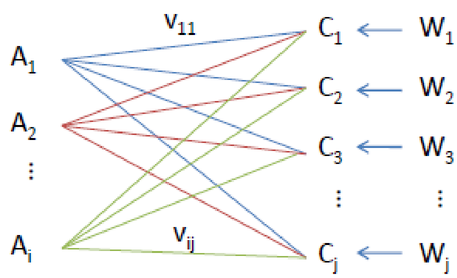

Fig. 1: Component of MCDM.

There are several MCDM [12-19], which have been extensively used in different fields, especially to rank alternatives. They are also used to evaluate and select problems.

2.1 TOPSIS Method

TOPSIS is based on the concept that the chosen alternative should have the shortest distance from the Positive Ideal Solution (PIS) and the furthest from the Negative Ideal Solution (NIS) [12]. The final ranking is obtained by means of the closeness index.

The TOPSIS procedure consists of the following steps:

- STEP 1: Establish a performance matrix
- STEP 2. Normalize the decision-matrix
- STEP 3. Calculate the weighted normalized decision matrix
- STEP 4. Determine the positive ideal and negative ideal solutions
- STEP 5. Calculate the separation measures
- STEP 6. Calculate the relative closeness to the ideal solution
- STEP 7. Rank the preference order

2.2. SAW Method

Simple Additive Weighting (SAW) which is also known as weighted linear combination or scoring methods is a simple multi attribute decision technique. The method is based on the weighted average. An evaluation score is calculated for each alternative by multiplying the scaled value given to the alternative of that attribute with the weights of relative importance directly assigned by decision maker followed by the sum of the products for all criteria. Process of SAW consist of these steps [14]:

- STEP 1: Establish a decision matrix (m × n) that includes m alternatives and n criteria
- STEP 2: Calculate the normalized decision matrix for positive criteria and negative criteria
- STEP 3: Evaluate each alternative by a weighing average taking into account the criteria weights

2.3. PROMETHEE Method

The PROMETHEE family of outranking methods, including the PROMETHEE I for partial ranking of the alternatives and the PROMETHEE II for complete ranking of the alternatives, were developed by Brans [13]. The Promethee I and II procedures consist of the following steps:

- STEP 1: Determination of deviations based on pairwise comparison. Deviation denotes the difference between the evaluations of two alternatives in each criterion
- STEP 2: Application of preference function
- STEP 3: Calculation of an overall or global preference index by the weighted average of deviations
- STEP 4: Calculation of positive and negative outranking flows (Promethee I) for each alternative taking into account the overall preference index
- STEP 5: Calculation of net outranking flow (Promethee II) by subtracting positive and negative outranking flows

Topsis, SAW and Promethee methods are applied in section 5 for ranking solar photovoltaic plant locations.

3. Brief review of multi-criteria decision methods applications

Application of MCDM to solve different kinds of ranking problems has increased in the last years. Besides, there have been many variants of the first multi-criteria decision methods which have introduced fuzzy logic to the assessment.

Table 1 shows some fields where multi-criteria decision methods have been applied. The methods called "Other Methods" refer to those that have been adapted to particular fields. This means that, in order to obtain the ranking of the alternatives, they do not use classical methods but their own.

As it is shown in Table 1, there are fields where several methods have been applied such as the ranking of airlines (TOPSIS, VIKOR, and Other methods), ranking of websites (TOPSIS, PROMETHEE and Other methods), ranking of universities (TOPSIS and Other methods), ranking of hotels (DEA and TOPSIS), ranking of health care centers (TOPSIS and DEA) and ranking of banks (DEA and ELECTRE). This gives the idea; more than one method can be applied to obtain rankings in the same field.

However, these rankings may vary depending on the method used and even by varying parameters under the same methods. For example, the rankings obtained by the application of Promethee with Usual membership functions may be different from the ranking obtained by using with Gaussian membership functions. The same may happen with Electre, if the concordance, discordance or veto thresholds are changed. This means that an alternative may obtain a different ranking if it is evaluated by different methods.

Table 1. Examples of applications of multi-criteria decision methods.

Multi-criteria decision method	Field of application	Reference
TOPSIS [12]	Airlines	[20]
	Health care center	[21]
	Hotels	[22] ,[23]
	Websites	[24]
	Universities	[25]
PROMETHEE [13]	Hospital websites	[26]
VIKOR [15]	Airlines	[27],[28], [29],[30] [31]
AHP[16]	Fast-food restaurants	[32]
	Catering service	[33]
DEA [17, 18]	Banks	[34], [35]
	Hotels	[36]
	Health care center	[37], [38]
ELECTRE [19]	Banks	[39]
Other methods	Airports	[40]
	Railway operators	[41]
	Websites	[42], [43]
	Universities	[44]
	Airlines	[45]

Given this, it seems interesting to perform an analysis of those alternatives which are better than others if they are evaluated using more than one method.

This led us to the conclusion that many alternatives may be ranked in different ways according to the method and parameters used. Considering that each method is a function evaluated in each alternative, the idea of the Pareto Analysis to rank alternatives can be used. For example: if one alternative is worse than another in the rankings given by all the methods, it can be stated that one is dominated by the other, and no rational decision justify the selection of the dominated alternative.

In consequence, a Pareto analysis of the alternatives may be helpful to the decision maker.

4. Pareto Analysis

Pareto optimality is a well-known method proposed by the engineer, economist, and sociologist Vilfredo Pareto [46]. In summary, it defines how two alternatives, A_1 and A_2, are related.

The possible relationships between two alternatives are: domination or incomparable. Alternative A_1 dominates A_2 if $F_j(A_1) \geq F_j(A_2)$ for all criteria j with at least one inequality. Where $F_j(A_1)$ is the evaluation of alternative A_1 in criteria j and $F_j(A_2)$ is the evaluation of alternative A_2 in criteria j. If $F_j(A_1) \geq F_j(A_2)$ in some criteria and $F_j(A_1) \leq F_j(A_2)$ in others, then A_1 and A_2 are incomparable. Alternatives that are not dominated by any other are named Pareto optimal (PO) points (efficient points). The Pareto front is the set of PO points.

When applying various multi-criteria decision methods in the same set of alternatives and criteria, it may happen that an alternative obtains a position in one method and a different position in another. As a result, according to the method used, an alternative A_1 may be "better" than the A_2. However when applying another method, it may happen the opposite. To determine the best alternatives it is possible to apply the rankings of "Pareto Optimality" where you compare the position obtained by each alternative in each method. Dominance can be specified as follows:

<u>Dominance:</u>

A_1 dominates A_2 if and only if:

- $F_j(A_1) \geq F_j(A_2)$ for all applying methods ($1<j<m$) with at least one inequality

Where:

- $F_j(A_1)$ is the evaluation of alternative A_1 in the method j
- $F_j(A_2)$ is the evaluation of alternative A_2 in the method j
- m is the number of methods.

Those alternatives that are not "dominated" by any other will be called "Pareto optimal points", and they collectively constitute the so-called "Pareto front". The alternatives in the Pareto front are the best alternatives (Figure. 2).

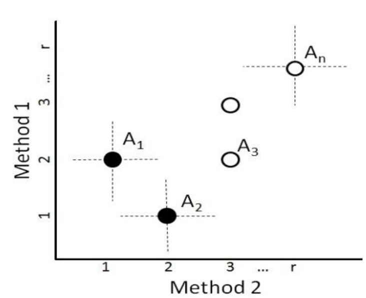

Fig. 2: Pareto front representation for a set of alternatives and two methods.

For example, the figure represents the rankings obtained for several alternatives (A_1, A_2,.., A_n) by using two methods (method 1 and method 2), where the best rating is the smallest (1) because it represents the first position, and the worst rating is the biggest (r) because it represents the last position.

In this case, all the alternatives represented by white dots are "dominated" by some other points. The points A_1 and A_2 have been dominated in some methods but not in others. Hence you can say they are incomparable among them (the alternative A_1 is better than the alternative A_2 in the evaluation by Method 2, but the alternative A_2 has better assessment than A_1 by Method 1). Therefore, these points have not been completely dominated and then, they form the set of the best alternatives.

This way you can set another ranking of two places: first, the non-dominated set of alternatives (A_1 and A_2), and second, the set of alternatives that are dominated among the rest of the other alternatives ($A_3 \ldots A_n$).

5. Case of Study

This case of study was developed using the information about places for implementing solar photovoltaic plants. Information was provided by the Graphic Expression department of the Polytechnic University of Cartagena. They have 538 different locations (alternatives) which are evaluated under 10 criteria. Eight out of 538 locations will be used in this paper. The purpose of the present section is to show the application of Pareto analysis in fields where more than one MCDM were applied. Table 2 presents the criteria and weights obtained in [47].

The expert evaluation was conducted through crisp values. Table 3 shows the assessment matrix for the 8 alternatives selected.

Topsis (T), Promethee II (P) and Simple Additive Weighting (SAW) are applied using the same matrix. It is not necessary to use the same criteria weights in all applied methods. In this example, same criteria weights are used for simplify the case of study, taking into account that the aim of the paper is to show Pareto analysis where many multi-criteria methods are applied. Table 4 shows the ranking obtained by the three methods applied.

Table 2. Criteria and weights used in the location of solar photovoltaic plants

Criteria	Description	Weights
C_1	Area (m^2)	0.1165
C_2	Distance to town or villages (m)	0.0537
C_3	Distance to electricity transformer substations (m)	0.1474
C_4	Distance to main roads (m)	0.1642
C_5	Distance to power lines (m)	0.0840
C_6	Agrological capacity (Classes)	0.1046
C_7	Slope (%)	0.0819
C_8	Solar radiation (KJ/m2·día)	0.1184
C_9	Average temperature (ºC)	0.0655
C_{10}	Field orientation (classes)	0.0638

Table 3. Evaluation matrix used in the location of solar photovoltaic plants

Criteria	A_1	A_2	A_3	A_4
C_1	26025	37590	34956	35138
C_2	1031	493	1234	270
C_3	1598	1209	1709	1126
C_4	464	24	406	25
C_5	0	0	0	0
C_6	2	1	2	2
C_7	1	1	1	1
C_8	2043	2041	2038	2045
C_9	18	18	18	18
C_{10}	4	2	4	5
	A_5	A_6	A_7	A_8
C_1	43749	75555	58477	45225
C_2	48	1581	1127	2016
C_3	1958	2104	1695	2584
C_4	24	849	569	222
C_5	27	0	0	0
C_6	3	2	2	1
C_7	0	1	1	1
C_8	2039	2047	2042	2047
C_9	18	18	18	18
C_{10}	4	4	4	2

Table 4. Ranking obtained by three multi-criteria methods applied

Alternatives	T	SAW	P
A_1	6	7	7
A_2	2	3	3
A_3	4	6	4
A_4	1	1	1
A_5	5	2	2
A_6	8	4	8
A_7	7	5	5
A_8	3	8	6

Non-dominated alternatives are obtained after applying Pareto analysis to the results shown in Table 4. The first set of Pareto front is composed of A_4 alternative because it has the first position in the three methods applied. In this case, there is no competition in the first Pareto front, but the second one is composed by A_2 and A_5 alternatives because there is no dominance between them. The third Pareto front is composed of A_3, A_6, A_7 and A_8 alternatives; thus, these alternatives are not dominated by any other in the same set.

Figure 3 shows the sets of Pareto-front representation for the Table 4 points. Positions obtained by SAW method are in X axis, by Promethee in Y axis and by Topsis in Z axis. Points represent alternatives and lines represent Pareto front.

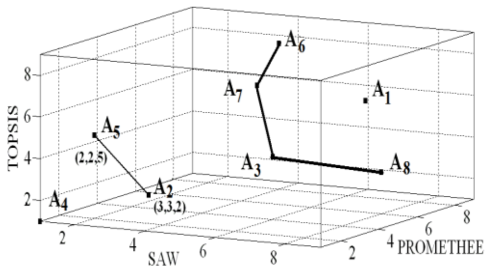

Fig. 3: Pareto front representation.

The alternative A_4 is the best and the only one which conforms to the first Pareto front. Alternatives A_2 and A_5 are incomparable and they conform to the second Pareto front together. The third Pareto front is composed of the alternatives A_3, A_6, A_7, and A_8. The worst alternative is $A_{1.}$ It's the only member of the fourth Pareto front because it is dominated by A_3.

Figure 4 shows the bar representation of the positions obtained by each alternative in the second case of study.

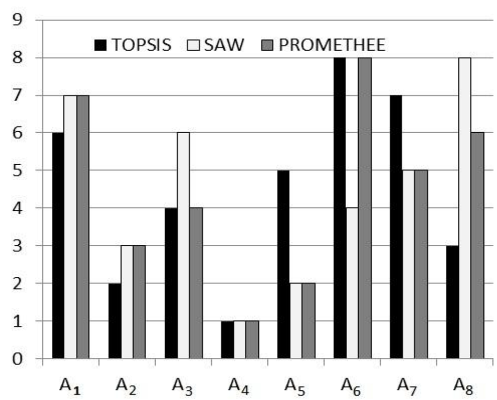

Fig. 4: Ranking representation of alternatives.

Obviously, the best positions are obtained by A_4 because it achieves the first position in the three rankings. Figure 4 shows that A_2 and A_5 obtain good positions in some methods, but the worst positions in others. Alternative A_5 obtains a bad position in Topsis method. Nevertheless, it shows good results when applying Promethee and SAW. Alternative A_2 doesn't obtain good results in Promethee and SAW, but in Topsis was the second. The positions obtained in the set of alternatives A_3, A_6, A_7 and A_8 are worse than the ones obtained in the set A_2 and A_5. That's the reason why they conform the third Pareto front. It's possible to notice that the alternatives A_6 and A_8 get the worst position in some methods, but have at least one acceptable position in others (SAW and Topsis respectively). Alternative A_1 is dominated by A_3 because its positions are worse than those of A_3 in all methods.

In this case, Pareto analysis gives information to decision makers, which could be used when the best alternatives are not available for any reason. That means that, in case A_4 is not available; decision makers can choose either, alternative A_5 or A_2, which are in the second Pareto front. The same could be made with the rest of Pareto fronts.

Three multi-criteria decision methods were applied in this case of study. Note that the number of decision methods is not limited. To obtain alternative order, other multi-criteria decision methods can be used, as well as other methods such as the Borda's [48].

Once the rankings are obtained by any of the multi-criteria decision methods, instead of applying the Pareto analysis, the Borda's method could be applied to reach a consensus. To do this, let suppose that the values of n, n-1,…,1 are assigned to the alternatives, taking into account the position obtained in each multi-criteria decision method. In this case, n=8 because there are 8 alternatives. Table 5 is similar to Table 4; it has a new column (total) which represents the total point obtained by each alternative according to Borda's method.

Table 5. Ranking obtained by Borda's method.

Alternatives	T	SAW	P	TOTAL
A_1	3	2	2	7
A_2	7	6	6	19
A_3	5	3	5	13
A_4	8	8	8	24
A_5	4	7	7	18
A_6	1	5	1	7
A_7	2	4	4	10
A_8	6	1	3	10

Table 5 shows how it is possible to obtain a new order by means of the Borda's method: A_4, A_2, A_5, A_3, A_7, A_8, A_6 and A_1. This order is similar to the result obtained by Pareto, although it was obtained by a different concept.

6. Conclusions

There are several fields in which more than one multi-criteria decision method for ranking alternatives could be applied. In these cases, each method can get a different ranking and it is necessary to make a consensus among these results. In this paper, Pareto analysis has been used to illustrate its usefulness when you have multiple alternatives and criteria, and each alternative has obtained different positions in each multi-criteria decision method applied. Using Pareto analysis it is possible to reduce the number of alternatives that a decision maker can choose. They only have to choose between those that compose the Pareto front. There is no reason to choose one of the alternatives out of the Pareto front because they were dominated by others; i.e. they are worse than the others. In other words, the decision maker can justify the choice of any of the alternatives in the Pareto front because none of them will be dominated by any other; hence, they all are as good and reasonable as the rest. Besides, the set of Pareto front helps decision makers in re-selected alternatives when the first options are not available for any reason. Finally Borda's method was applied as another possibility for obtain consensus. Similar results were shown, although Pareto analysis and Borda's method follow different concepts.

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