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Evaluation of suitable locations for the installation of solar thermoelectric power plants ☆

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ABSTRACT

The aim of the present paper is to determine the best location to host a solar thermoelectric power plant. We will seek to show how Geographic Information Systems (GIS) and Multi Criteria Decision Making (MCDM) such as the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS method) and Analytic Hierarchy Process (AHP), are an excellent combination to solve complex locations problems. The coast of the Region of Murcia in the southeast of Spain has been chosen as the study area to carry out this evaluation.

The GIS will be shown to be a very useful tool, since GIS are able to generate a database which serves as a starting point for conducting any decision support system. The posed problem will be resolved using restrictions to reduce the area of study, and the criteria that will influence the decision-making. These criteria will be of different natures; with quantitative criteria (numerical values) coexisting with qualitative criteria (labels and linguistic variables). In this article, AHP will be used to obtain the weights of the criteria, and the fuzzy TOPSIS method for the evaluation of the alternatives. In order to compare the results obtained with TOPSIS, the ELECTRE-TRI methodology will be applied.

1. Introduction

Through the collection of environmental data in the mid-twentieth century it was envisioned that the atmospheric concentrations of CO_2, the main gas causing the greenhouse effect (Arrhenius, 1896), were growing at an alarming rate and leading to changes in the climatic conditions of the planet. As a result, the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO), created the Intergovernmental Panel on Climate Change (IPCC) with the aim of promoting supportive policies worldwide (United Nations, 1992/1997/2013; Working Group I, 1990). In the early 21st century the implantation of Renewable Energy (RE) facilities was encouraged through sustainable development strategies, in order to fulfill the various energies policies of the European Union (European Commission, 1996, 1997).

In Spain, the main reasons for developing a RE plan for 2005–2010 (Institute for Energy Diversification, 2005) were the necessary containment of growth in emissions of greenhouse gases and compliance with the stated objectives of the European Union. This plan contained the commitment to reach a level of at least 12% of total energy consumption in Spain in 2010 using RE sources. That objective was attained, since in that year 13.1% of the gross energy consumption in Spain was covered by RE facilities (Fig. 1). The continuous application of energies policies to support RE in the European Union (European Parliament, 2009) led to a remarkable growth in Spain. The initial values set were exceeded to such an extent (Fig. 1) that they also drove the development of a new action plan for 2011–2020 (Institute for Energy Diversification, 2010) with a far more ambitious objective: that of achieving a 20% share of energy from renewable sources in energy consumption by 2020.

Spain is located between 36°N and 43°50′N, and between the meridians 9°W and 3°E, which means that the number of sunny days per year is very high. Therefore, the implementation of solar thermoelectric farms is a recommended alternative since the contribution of solar thermoelectric energy to fulfil the targets set for 2020 is estimated at 15,353 GW h. This means that for the year 2020, solar thermoelectric power plants should have been installed giving a total installed capacity of 5079 MW. To do so, the first stage is to determine which areas are suitable and which are unsuitable for that purpose. The restrictions which make an area

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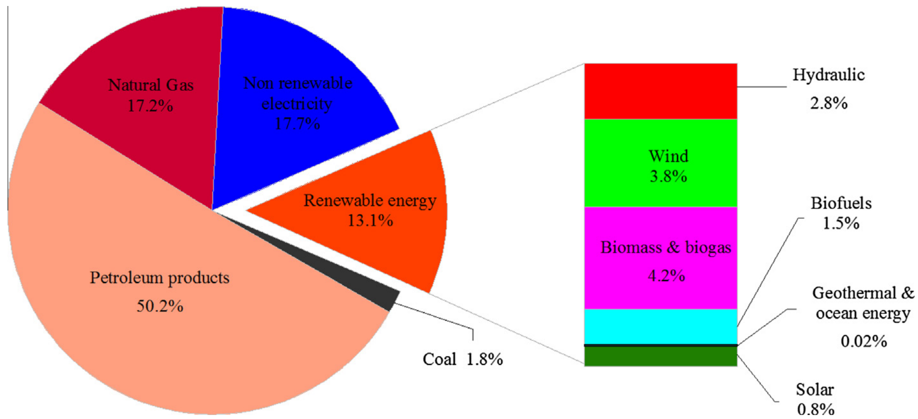

Fig. 1. Gross final energy consumption in 2010 in Spain (Institute for Energy Diversification, 2010).

unacceptable for the implementation of a solar farm must be taken into account. Such facilities should be located away from cities or towns, protected areas such as archaeological or paleontological sites as seen in Table 1, which will be discussed below. The first problem arises here, which is to obtain viable areas to implement this type of facilities. To achieve this, GIS are very useful tools, since they are not only able to analyse and visualise geospatial information but can also generate a database which serves as a starting point for conducting any decision support system (Domínguez & Amador, 2007). However, it is not only necessary to establish suitable locations, but also to obtain the optimal locations. Methodologies such as MCDM assist decision makers in solving the problem, since the most suitable plots for the installation of a solar thermoelectric power plant can be determined through their use.

MCDM are successfully used in many different planning processes. Although different MCDM exist, all of them follow a number of steps: problem definition, identification of alternatives, criteria selection, preparation of the decision matrix, and assigning weights to the criteria. MCDM are also important methods for analysing data, providing the flexibility and ability to promote the development and implementation of RE (Chang & Chen, 2010). There are a great deal of MCDM used in the analysis of energy policies (Pohekar & Ramachandran, 2004): Multi-Attribute utility; the outranking methods such as ELimination Et Choix Traduisant la Realité (ELECTRE) (Roy, 1968); and The Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) (Brans, Mareschal, & Vincke, 1984); The Analytic Hierarchy Process (AHP) (Saaty, 1980); or The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Hwang & Yoon, 1981).

However, the information which is required for the assessment of the criteria is not always numerical and moreover it is sometimes imprecise and affected by uncertainty or vagueness. Therefore, on many occasions rather than dealing with the problem with numerical variables (Garcia-Cascales & Lamata, 2009), it is advisable to work with linguistic variables (Phillis & Andriantiatsaholiniaina, 2001; Doukas, Andreas, & Psarras, 2007). This entails carrying out arithmetic processing through fuzzy numbers; thus, the linguistic variables take values from a set of defined linguistic terms and the semantics are represented by the corresponding fuzzy sets. To date, many fuzzy MCDM methods have been developed (Kuo, Chi, & Kao, 1999; Ayağ & Özdemir, 2009; Kahraman, Çevik, Ates, & Gülbay, 2007; Ölcer & Odabasi, 2005; Chiou, Tzeng, & Cheng, 2005).

The use of outranking techniques is not appropriate when the number of alternatives and criteria are very high, since this makes the number of comparisons impossible to carry out. Conversely,

Table 1
Layers of restrictions.

N.	Denomination of the layers of restrictions
1	Urban lands
2	Protected and undeveloped lands
3	Areas of high landscape value
4	Water infrastructure, military zones and cattle trails
5	Watercourses and streams
6	Archaeological sites
7	Paleontological sites
8	Cultural heritage
9	Roads and Railroad network
10	Community Interest Sites (LICs)
11	Areas of special protection for birds (ZEPAs)
12	Mediterranean coast
13	Mountains

the utility-based method is also beneficial when there are linguistic as well as numerical criteria. Therefore the most suitable options, from our point of view, to solve this sort of problems are VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) (Opricovic & Tzeng, 2004) and TOPSIS (Hwang & Yoon, 1981; Opricovic & Tzeng, 2003).

For all the above reasons, and given its ease of calculation, in order to solve the proposed problem the Fuzzy TOPSIS method has been chosen. This method is based on the concept that the alternative chosen should have the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution. In the literature there is a considerable number of works that have incorporated fuzzy numbers to the process as well as linguistic variables (Garcia-Cascales & Lamata, 2011; Kuo, Tzeng, & Huang, 2007; Li, 1999). It should also be kept in mind that when working with multiple criteria decision methods such as AHP, ELECTRE, PROMETHEE, and TOPSIS, we risk falling into the problem of Rank reversal (Garcia-Cascales & Lamata, 2012). When there are a large number of alternatives, adding or deleting one or more alternatives will not influence the final result and, in this case the problem of Rank reversal can be ignored. It is known that Rank Reversal in TOPSIS is due to the fact that the reference points (the positive ideal solution-PIS and negative ideal solution-NIS) may modify depending on the assessments of the alternatives (Garcia-Cascales & Lamata, 2012). However, when there is a large number of alternatives (32,906 alternatives in this case), there could be more than one alternative with the same extreme values. Therefore, adding or removing some alternative will not influence the final result.