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Multicriteria assessment in GIS environments for siting biomass plants

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ABSTRACT

This paper presents a complete multicriteria assessment process in GIS environments for the identification of sites suitable for building biomass plants. To achieve this aim, the principal criteria were defined (factors and constraints), evaluated and weighted in the context of Saaty's analytic hierarchies and divided into three groups: environmental, economic and social. The best alternatives were obtained after applying the two decision rules: weighted linear summation (WLS) and ideal point method (IPM). The final stage of the decision problem consisted of a sensitivity analysis of the set of factors and their associated weights using two global methods based on variance, the Sobolĭ and the extended-FAST methods. The model was applied in an area of the European Mediterranean Region (Valencia, Spain) where agriculture and forest are representative land uses. The MCA-GIS analysis concluded that the most suitable areas for siting the biomass plant are located near residential zones, by allocating for this purpose only 23% of total area. The sensitivity analysis provided insight into the most influent factors on the model for aiding energy planning decisions, such as physiography, crop types, vegetation, potential demand and transport cost.

Introduction

GIS-MCA techniques have been applied within a large number of disciplines, using the appropriate criteria and factors, such as town and rural planning, choosing a site for different types of installation, ground-use maps, reducing natural risks and environmental impact, distribution of limited resources, etc. (Bórdas, 2006; Mena et al., 2006; Sumathi et al., 2008; Malczewski and Jackson, 2000). One of the first multicriteria assessment studies in the context of renewable energies, dealing with wind-generated electricity, was carried out by Voivontas (1998), who developed a DSS to estimate the maximum obtainable generating potential in Crete (Greece). Another study by Grabaum and Meyer (1998) used GIS-MCA for regional planning and development in Germany and focused on functional evaluation methods to minimize the conflict between ground use and environmental impact. Chen et al. (2001) followed the same line, combining MCE and GIS to evaluate natural risks and presented three different evaluation methods for the same analysis, using a comparison of the results as an aid to subsequent decision making. The three methods he used were: weighted linear summation (WLS), techniques for order preference by similarity to an ideal solution (TOPSIS) and compromise programming (CP). Studies using MCA-GIS techniques in the context of renewable energies include Cheng-Dar and Grant Gwo-Liang (2007) in Taiwan and Butchholz et al. (2009) in Uganda. The former was carried out in a GIS environment to assess the viability of local renewable energy sources as a source of investment. The latter focused on determining criteria and assigning weights in the renewable energies field to facilitate the design and implementation of sustainable bio-energy projects by applying and comparing four decision tools: Super Decisions, DecideIT, Decision Lab and NAIADE. In forestry, Mitchell (2000) proposed a decision support system (DSS) for bioenergy applications in the form of a model that combines biomass production, conversion and electricity generation.

Multi-criteria evaluation must always finish off with a sensitivity analysis as the last step in all decision problems, as in the case of Crosetto and Tarantola (2001), who establishes a clear distinction between an uncertainty analysis (Morris method) and a sensitivity analysis in the true sense of the term using the Sobol' and extended-FAST methods. Both these analyses can be used in the planning stage with GIS tools to optimize the assignment of resources when acquiring spatial data. Also following the general line of the above-cited authors but in the field of hydrology, DĭOvidio and Pagano (2009) proposes a stochastic approach (as opposed to the traditional determinist model) for the optimal design of bio-mass plants by comparing different technological solutions (steam generation, gas cycle and combined cycle).

This paper focuses on identifying suitable areas for locating biomass plants in response to the European strategy for promoting renewable energies. Using biomass to generate energy has many

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advantages and provides important benefits (Commission of the European Communities, 2005). The MCA-GIS method was used to help in taking decisions on land-use issues, in this case as an Energy Spatial Decision Support System (ESDSS).

Materials and methods

The study area and data sources

Utiel-Requena is a region of the province of Valencia (Spain), divided into nine municipal areas. On the northern side it is bounded by the provinces of Cuenca and Albacete in the Community of Castilla – La Mancha and on the north-east, east and south-east by other regions of the Community of Valencia. It has a river, the Magro, which rises in Utiel and flows along a relatively flat plateau with an average height of 750 m. The region covers an area of 1831 km^2 and has a population of 40,735. Agricultural activities occupy an area of 669 km^2, with the main crops being grapes for wine-making, olives and fruit. Forest areas make up a total of 615 km^2, with a predominance of pinus halepensis. Using the proposed method, total recoverable biomass was calculated to be 110,547 t.

Utiel-Requena is covered by sheet numbers 665, 666, 693, 694, 718, 719, 720, 744 and 745 of the National Topographical Maps on a scale of 1:50,000 (MTN25). The reference system is the European Datum 1950, UTM Projection (Universal Transverse Mercator) in the 30 North zone. Information for the study was obtained from the following sources:

- National Statistics Institute (Agricultural and Population Census) with the purpose of knowing the amount of population per municipality (National Statistics Institute, 2008).
- Spanish Crop and land use map. Cartography on a 1:50,000 scale, differentiating between different crop types with the purpose of calculating agriculture biomass (Ministry of Agriculture, Fisheries and Food, 2008).
- Third National Forestry Inventory (IFN2 and IFN3). Digital cartography on a 1:50,000 scale with the purpose of calculating forestry biomass (Ministry of Environment and Rural and Marine, 2008).
- National Area Orthophotogrametry Plan (PNOA), with the purpose of generating a slope map. BCN25: Numeric Cartographic Base 1:25,000, with the purpose of having a base cartography (National Geographic Institute, 2008).
- Lithological, geomorphological cartography and physiography with the purpose of knowing the main characteristics of the terrain (Map thematic series, 1998).
- Natural and protected spatial cartography of the areas under study in Natura2000 Network with the purpose of taking into account the environmental issues Cartography of Natura2000 Network (2008).
- Fifth level Corine Land Cover, European land occupation database with reference scale 1:100,000 (National Geographic Institute, 2008).
- Data and results of the research project carried out by the Instituto de Ingeniería Energética (Institute of Energy Engineering, I.I.E.) from 2007 to 2009 in a GIS environment (Perpiñá, 2008; Perpiña et al., 2009), with the aim of defining a general methodology for the use of residual agricultural and forestry biomass to generate power, including the quantification and location of biomass, transport strategies, and presentation of graphic and statistical results. It should be noted that the information thus acquired on biomass distribution (t/ha), transport costs (€/t) and potential demand (ktoe) are used in this paper (see Table 1).

Methodology

The location problem dealt with in this paper is directly linked to determining the most suitable areas for building a local biomass plant. The scheme in Fig. 1 shows the steps involved in the process.

Selecting spatial criteria: factors and constraints

The most important phase and the one with a strong influence in the evaluation of potential sites for an installation or activity is the selection of the factors and criteria that will have a direct influence on the activity/facility in question. As can be expected, many different factors can be taken into account in land studies and those finally selected will be in accordance with the required objectives, the information available, planner's experience, etc. In the present study all the criteria (factors and constraints, see Tables 1 and 2) are reflected in the corresponding GIS thematic classes consulted from an extensive bibliography (Voivontas, 1998; Gómez and Barredo, 2005; Bosque, 2002; Bosque and Moreno, 2004; Gómez, 1992; Hubina and Ghribi, 2008; Munier, 2004). Experts were also consulted and the current standards were complied with.

Here it should be pointed out that the territory contains both natural and artificial areas with special characteristics that need to be preserved, many of which are protected by current legislation. These areas have been considered as constraints in the present study (see Table 2). The ground-use regulations identify the areas where these plants can be built, known as Common Non Urbanisable Land, on the Valencia Community's land classification maps (Conselleria dǐobres públiques urbanisme y transport, 1999).

Natural areas, protected zones, elements of the national heritage, natural monuments, flora, fauna, paleontological, archaeological and scientific sites, etc. are considered as irreplaceable assets and are subject to protection and conservation measures. In practice, this means that all such elements are surrounded by a protection area in which all building is forbidden, as laid down by the Valencia Parliament (Law 11/1994 of 27 December, 1995) and Spanish legislation (Law 16/1985 of 29 June on the Spanish National Heritage, 1985).

Valuation of factors

Pairwise comparison matrices were used with Expert Choice software (Expert Choice, 2009) in order to value the selected factors and their classes. Each criterion/factor is assigned an established Value_{ij} from each class in order to determine numerical values calculated from the pairwise comparison matrices.

The aim was to determine the final values of each factor (Value_{ij}) in each of the hierarchies and to obtain the matrix consistency ratios (CR), which indicate the arithmetic consistency of the values assigned in each matrix, according to Eq. (1):

$$CR = \frac{CI}{RI} \tag{1}$$

where $CI = (\lambda_{max} - n)/(n - 1)$, λ being a value obtained from the product of the normalised principal eigenvector multiplied by the comparison matrix, and n is the number of factors (or classes) in the comparison matrix. The random index (RI) is the reciprocal diagonal matrix between the values $1.59 > RI > 0$, RI being = 0 for $n = 1$ and RI = 1.59 for $n = 15$) (Malczewski, 1999).

After obtaining the values of the set of factors, they are then weighted by Saaty's Analytic Hierarchy method so as to be able to establish hierarchies of relative importance. This involves using pairwise comparisons with a scale of values between 1 and 9 using value judgements to compare sub-categories two by two. In this process 1 indicates equally preferred and 9 is extremely preferred and, in practice, consists of completing all matrix cells (*aij*) by these values and their reciprocals (Gómez and Barredo, 2005; Malczewski, 1999).