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Optimal location of a biomass power plant in the province of Granada analyzed by multi-criteria evaluation using appropriate Geographic Information System according to the Analytic Hierarchy Process

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Abstract. Nowadays renewable energies are in a period of growth, which favours the birth of numerous researches like, for example, this study about the analysis of the optimal location of a biomass power plant in the province of Granada (Spain).

So, the study will be developed using Geographic Information System (GIS) and Multi-Criteria Evaluation (MCE) according to the Analytic Hierarchy Process (AHP). And the main target will be to determine the welcome capacity of the territory to this type of plants.

Key words

Analytic Hierarchy Process (AHP), Biomass, Geographic Information System (GIS), Multi-criteria Evaluation (MCE), Optimal location

1. Introduction

Nowadays renewable energies are in a period of growth especially because of the last changes in the European and national rules. For example, the Junta de Andalucía (Regional Government of Andalusia), in its "Plan Andaluz para la Sostenibilidad Energética 2007-2013" (Andalusian Plan for the Energetic Sustainability 2007-2013), that includes every legal actuation line about energetic matters, suggests only the use of energies of renewable origin to achieve its aims.

As a response to these requirements, a lot of studies appear trying to understand renewable energies in depth: origins, methods of exploitation and management, how to improve the performance and so on [1 - 3].

In this context, and taking into account the big potential of biomass in Granada, we have developed this study to find the area with the best reception capacity to implant a biomass plant in the province.

The method used to achieve our aim is based in a multi-criteria evaluation (MCE) using appropriate geographic information system (GIS) according to the analytic hierarchy process (AHP). The basic problem in this method is due to the fact that numerous variables take part in it and it is very difficult to consider them all.

2. Background

In this section, we specify the techniques our method is based on. Thus, we can say that it is based on three main techniques:

1) *Geographic Information System (GIS)*: It is a technology for creating, storing, analyzing and managing spatial data and their associated attributes [4].
2) *Multi-criteria Evaluation (MCE)*: It is a set of techniques that can provide a number of alternatives based on certain criteria, incorporating the structure of decision-maker preferences [5].
3) *Analytic Hierarchy Process (AHP):* It is a particular technique of MCE that solves the decision problem through a process of pairwise comparison of criteria and where the user's opinion is taken into account through the relative weight he assigns to each of these criteria.

The advantage of using GIS jointly with the AHP is that this methodology will allow us to verify whether the ratings given to each criterion have been successful by calculating the consistency ratio (*CR*). So, the value of this index must be less than or equal to 0.1.

3. System developed

The steps of our method are summarized in Fig. 1. Each step is now explained:

A. Identify factors

First of all, we establish the factors involved in the process, distinguishing between analysis criteria (AC) and exclusion criteria (EC).

The first ones will be used in the MCE. They are as follows:

1) *Energy potential:* Each land type has a different energy content depending on the vegetation on it. This value in kcal/kg will be taken into account to obtain the energy potential of the area.
2) *Availability of biomass:* This is the most important factor and depends on the rate of waste (t/ha) of biomass that could be generated in a given area according to the land type in question.
3) *Highway knots accessibility:* We will seek an area with a good transport infrastructure and, in particular, with easy access to highways to try to reduce the economic and energetic costs in the raw materials transport where possible.
4) *Protected natural areas:* This factor has two aspects. On one hand, the plant cannot be built in any area designated as "protected natural" but, on the other hand, we are interested in the plant being placed close to these areas because they are often sites of high biomass waste generation.

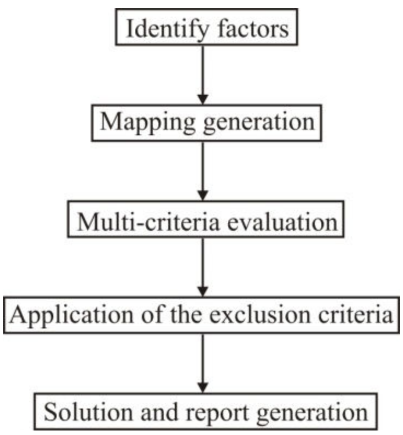

Fig. 1. Process diagram of the system developed for optimal location of a biomass plant analysis

And the latters will be used in obtaining the final solution from map of alternatives that has resulted in implementing that evaluation and are as follows:

1) *Existence of other biomass plant:* The presence of an existing biomass plant can mean a decrease in the amount of biofuel available for the new one. Therefore, in our case, it is necessary to know the effect of the existing plant in order not to harm our future plant.
2) *Grid distance:* Alternatives close to the electricity distribution network will have higher preference due to significant economic savings as well as a reduced environmental impact by not demanding new electricity infrastructure.
3) *Availability of water:* The presence of large sheets of water will also allow us to choose between the different alternatives.
4) *Influence area of the plant:* Among all the possible alternatives, we will consider as the final solution the one with largest influence radius, this is, having more suitable area in its surroundings.

B. Mapping generation

This second phase consists in obtaining a cartographic map for each of the analysis criteria that have been defined previously, from the existing public mapping.

These input issues, which in principle are in vector format, will be converted to raster format and reclassified in order to get discrete items that take values from 1 to 7, 1 being the best of all. Thus, the mapping will be completely normalized.

The maps produced will be, therefore, the following:

1) *Cartographic map about energy potential* (Fig. 2*):* It has been obtained from the "Land Uses Map of Andalucía", giving each of them its corresponding energy content and discretizing according to the values shown in Table I.

Table I. – Discretization values of the map in Fig. 2

CONTINUOUS VALUES (kcal/kg · year)	DISCRETE VALUES
0 - 3000	7
3000 - 4200	3
> 4200	1

2) *Cartographic map about availability of biomass* (Fig. 3*):* It has been obtained from the "Land Uses Map of Andalucía" too, giving each of them its corresponding rate of waste. The discretization values shown in Table II.

Table II. – Discretization values of the map in Fig. 3

CONTINUOUS VALUES (t/ha · year)	DISCRETE VALUES
0 - 0.3	6
0.3 - 1	5
1 - 3	4
3 - 4	3
4 - 5	2
> 5	1

3) *Cartographic map about highway knots accessibility* (Fig. 4*):* It has been obtained from

the “Road Map of Andalucía” and from the “Earrings Map” through cost-distance analysis of the friction surface that is created. The discretization is done according to Table III.

Table III. – Discretization values of the map in Fig. 4

CONTINUOUS VALUES (minutes to the nearest highway knot)	DISCRETE VALUES
0 - 5	1
5 - 15	2
15 - 30	3
30 - 60	4
60 - 90	5
90 - 120	6
> 120	7

4) *Cartographic map about protected natural areas* (Fig. 5*):* It has been obtained from the “Natural areas of Andalucía” and using the following discretization values in Table IV:

Table IV. – Discretization values of the map in Fig. 5

CONTINUOUS VALUES	DISCRETE VALUES
Not protected natural area	1
Protected natural area	7

C. Multi-criteria evaluation

MCE is performed using the analytical hierarchy process through the ArcGis extension called “AHP”. Thus, all previous maps will serve as input mapping for the MCE.

The process followed is:

1) *Matrix of preference generation*: This matrix, called comparative matrix, is square and has a dimension n equivalent to the number of criteria used. The a_{ij} terms correspond to the values obtained for all pairwise comparisons according to Table V.
2) *Verifying validity of the assigned weights:* Although the allocation of value judgment is based on well-established criteria, it always leads to a greater or lesser share of uncertainty and subjectivity, since in all human decision-making process these factors are inevitable.

Therefore, to verify that there is no conflict when considering together the pairwise comparison values of all criteria, we will obtain the following parameters:

- Principal eigenvector.
- Relative weight (w_j): It is a value given to each analysis criteria and it describes, accurately, the characteristics of the considered value judgments.
- Maximum vector: It establishes an operational measure of consistency in assigning value judgments.
- Consistency ratio (*CR*): The value of this index determines whether the allocation of weights is consistent or not. Thus, if *CR* is greater than 0.1, the allocation is inconsistent and we will have to change it.

3) *Automatic superposition of all input mapping*: ArcGis software through the AHP extension gives each map the weight of the analysis criteria it represents and carries out the automatic superposition after verifying the correct value of the consistency ratio ($CR \leq 0.1$).
4) *Map of territory's reception capacity*: The MCE solution that is obtained after implementing this process is a map of aptitude and capacity of reception of the territory to host a biomass plant. This map reflects the possible optimal locations for the biomass plant.

Table V. – Values to the pairwise comparisons (relative weights)

VALUES	MEANING
1	Both elements are equally important and contribute to ownership in the same way
3	Moderate importance of one element over another.
5	Strong importance of one element over another.
7	Very strong importance of one element over another. An element is strongly dominant.
9	Extreme importance of one element over another. One element is favored, at least an order of magnitude of difference.
2,4,6,8	Intermediate used as consensus values between two trials.

D. Application of the exclusion criteria

This phase consists in applying on the map of territory's reception capacity each of the exclusion criteria defined above to determine, among all these locations, the one that most interests us.

The GIS software is used again and, in particular, the Weighted Overlay process which produces an output item that combines the characteristics of various input items.

In our particular case, it will be the final solution map that combines all features and limitations specified previously in the exclusion criteria.

E. Solution and report generation

The final solution is the optimal ubication of a biomass plant within a given territory. The report should contain all the information about the study: geographical data, parameters considered for each of the criteria, values of the matrix of preferences, values of the pairwise comparisons, etc.; as well as the final solution and other characteristics that were considered as appropriate.

4. Case study

The developed method has been applied to the province of Granada in Southern Spain. We describe below the results obtained in each of the system's phases.

A. Identify factors

The factors considered are described in section 3.A.

B. Mapping generation

Thematic maps about the analysis criteria are those described at chapter 3.B., taking into account the same discretization values already specified (see Fig. 2-5):

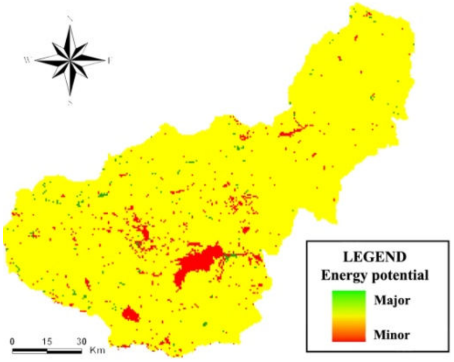

Fig. 2. Cartographic map about energy potential

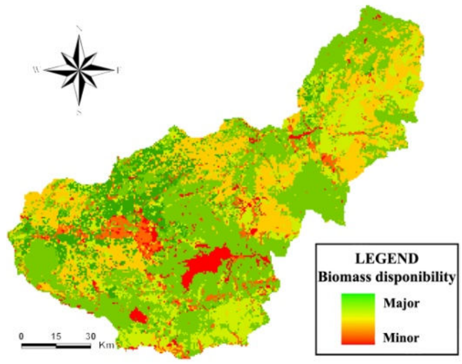

Fig. 3. Cartographic map about availability of biomass

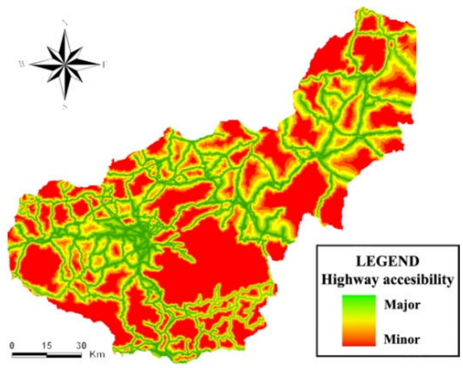

Fig.4. Cartographic map about highway knots accessibility

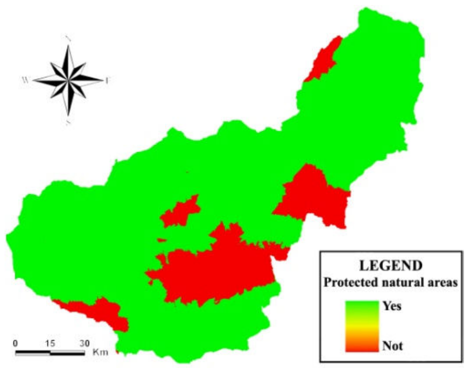

Fig. 5. Cartographic map about protected natural areas

C. Multi-criteria evaluation

In our case, the following matrix of preferences is define in Table VI.

Table VI. – Matrix of preferences

CRITERIA	Energy potential	Availability of biomass	Highway knots accessibility	Protected natural areas
Energy potential	1	1/9	1/5	1/9
Availability of biomass	9	1	5	1
Highway knots accessibility	5	1/5	1	1/5
Protected natural areas	9	1	5	1

Thus, once the matrix of preferences is introduced in the software, it provides all the necessary calculations required for MCE. The parameters obtained are as detailed at chapter 3.C.2 and their values are shown in Table VII.

Table VII. – Parameter values of the matrix of preferences

PARAMETERS	VALUES
Principal eigenvector	4.1331 0 -0.0666 -0.0666
Relative weights (w_j)	0.0374 → Energy potential 0.4244 → Availability of biomass waste 0.1138 → Highway knots accessibility 0.4244 → Protected natural areas
Maximum vector	0.6934 0.1860 0.6934 0.0610
Consistency ratio (CR)	CR = 0.0493

Given that the value of the consistency ratio is smaller than 0.1, it is not necessary to review the allocation of preference values as it is consistent.

So, the next step that the GIS program makes is the combination of all input items (analysis criteria mapping) but considering the importance each of them should have, i.e. their relative weights (w_j).

Finally we obtain the map of territory's reception capacity (Fig. 6) which is only the output theme obtained as the MCE solution using a GIS software according to the AHP. This cartographic map shows the greater or lesser capacity of the land for the reception of a biomass plant.

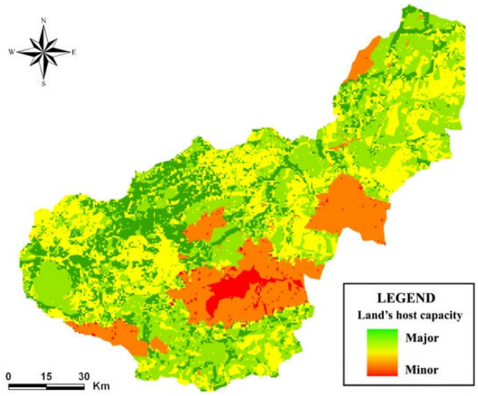

Fig. 6. Cartographic map of territory's reception capacity

The greener areas are the most suitable to serve as a solution to what we are looking for.

D. Application of the exclusion criteria

Once the MCE has finished and obtained the map of alternatives, we have made a final analysis based on the exclusion criteria. The ranges of values considered for each of these criteria have been:

1) *Availability of water:* The distance to large water areas, such as reservoirs or rivers, should not exceed fifteen kilometres.
2) *Grid distance:* The distance to power lines of high or medium voltage should be less than or equal to three kilometres.
3) *Existence of other biomass plant:* Our location should not be affected by the zone of influence of the existing biomass plant in Moclín, which includes the municipalities of Colomera, Íllora, Moclín and Pinos Puente.
4) *Influence area of the plant:* The zone of influence of the alternative in question should always cover as much area as possible. For this reason, when the other factors are equal, the final solution will have the largest area of influence.

Thus, our analysis based on exclusion criteria can be divided into two stages:

1) *Stage 1:* The map of territory's reception capacity was analyzed based on the first three exclusion criteria and, with this, we found three possible points to the optimal location of the biomass power plant (Fig. 7).

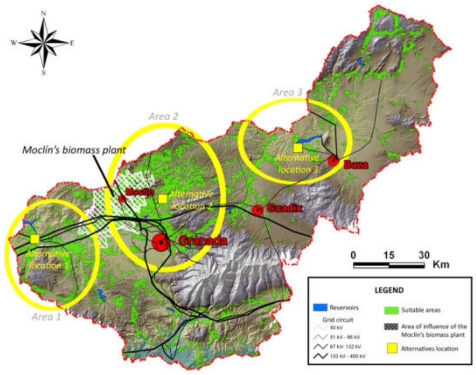

Fig. 7. Cartographic map of alternatives

Table VIII. – Areas and ratios of influence of each the alternative locations

ALTERNATIVES	INFLUENCE AREA (ha)	INFLUENCE RATIO (km)
1	29.986	25
2	**38.248**	**22**
3	11.841	20

2) *Stage 2:* We made an estimated calculation of suitable area that lies within each of the zone of influence that would appear if the biomass plant was located in each of the three alternative locations. The solution is the alternative with larger area, since as mentioned earlier, this allows for greater area of influence and is the one shown in Fig. 8, as supported by Table VIII.

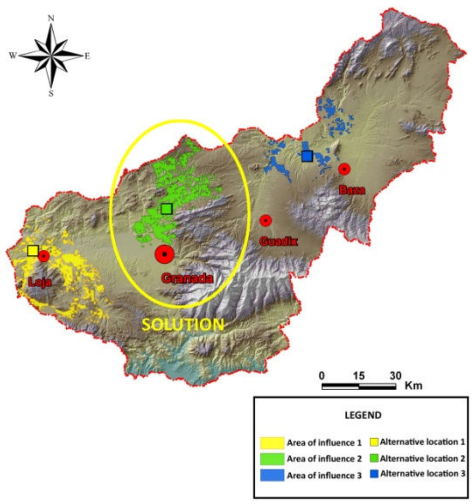

Fig. 8. Cartographic map of the final solution

E. Solution and report generation

After our study, we decided that the biomass plant would be located in the municipality of Deifontes and would have an influence ratio of 22 kilometres and an influence area of 38,000 hectares. The towns of Albolote, Alfacar, Atarfe, Calicasas, Campotéjar, Cogollos Vega, Deifontes, Güevejar, Iznalloz, Jun, Montejícar, Peligros, Piñar and Pulianas are in that area too. Moreover, that location lies a few kilometers from the Cubillas Reservoir with 18.7 hm^3 of capacity, so the needs of water that our biomass plant might have would be fully covered (Fig.9). And secondly, there is also a considerable availability of biomass, as we see in Fig. 10.

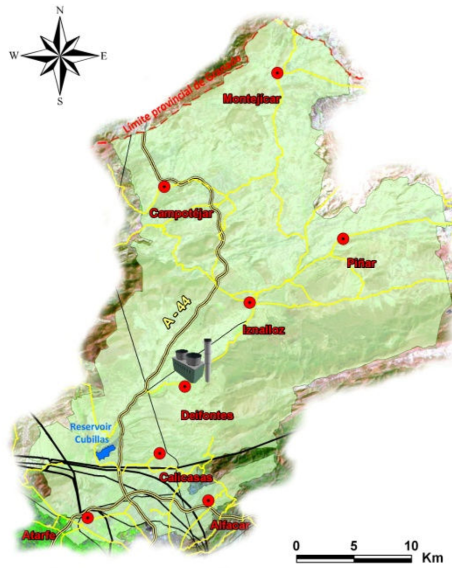

Fig. 9. Deifontes' biomass plant

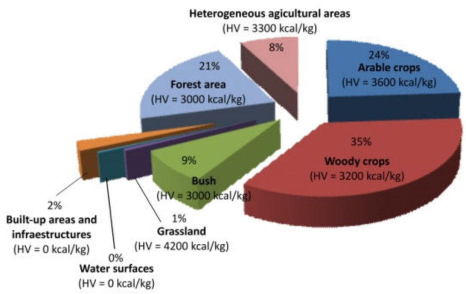

Fig. 10. Distribution of waste of biomass

Finally, the energy production that this plant could produce is estimated [6], under optimal conditions and yields of 100%, using,

$$P = AB \cdot EP \cdot A \cdot 1.32 \cdot 10^{-10}$$

where:

P: Theoretical energy production (MW)
AB: Availability of biomass (t/ha)
EP: Energy production (kcal/kg)
A: Area (ha)

Thus, the result obtained has been a theoretical energy production of 54.28 MW.

5. Conclusions

Through this study we have demonstrated the ease with which you can use a GIS software and the many possibilities allowed thanks to its numerous tools and extensions. Our system, supported by ArcGis, is based on the analysis of the territory through a multi-criteria evaluation according to the analytic hierarchy process in order to determine the optimal biomass plant location. Thus, after we established the guidelines to follow and described the whole process of analysis, it was considered desirable to apply it to the province of Granada.

The results have been very positive and give an idea of the validity of the method since each of the alternative locations found are equivalent to a real biomass plant proposal. In this way, alternative locations 1 and 3 correspond to the current proposed installation of a biomass plant in the municipalities of Caniles and Salar, respectively. And the solution (alternative location 2) is very close to the existing biomass plant in Moclín.

Finally, just mention that this work lefts open an important research field in the general topic of application of GIS to solving problems related to renewable energy and, in particular, in the subjetct of biomass.

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