Forest biomass plant site selection using multicriteria spatial analysis: **The study case of Beira Baixa, Portugal**

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Abstract

In this study we developed a decision support system based on multicriteria spatial analysis in order to select sites suitable to locate biomass plants. A set of environmental, economic and social criteria was defined, evaluated and weighted in the context of Saaty's analytic hierarchies. The best alternatives were obtained after applying Analytic Hierarchy Process (AHP). The model was applied to the central region of Portugal where forest and agriculture are the most representative land uses. Finally, sensitivity analysis of the set of factors and their associated weights was performed to test the robustness of the model. The proposed evaluation model provides a valuable reference for decision makers in establishing a standardized means of selecting the optimal location for new biomass plants.

Introduction

GIS-MCA techniques have been applied within a large number of disciplines, using the appropriate criteria and factors, such as urban and rural planning, choosing a site for different types of structures, land use maps, natural hazards and environmental impact, 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. Studies using MCA-GIS techniques in the context of renewable energies include Cheng-Dar and Grant Gwo-Liang (2007), Butchholz et al. (2009), Zhang et al. (2011) and Perpiña et al. (2012). 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.

Recently Mardani et al. (2015) published a systematic review of MCDM techniques and approaches in solving sustainable and renewable energy systems problems. AHP/fuzzy AHP and integrated methods were the most used in last years. The authors also emphasize that MCDM techniques can assist stakeholders and decision makers in unravelling some of the uncertainties inherent in environmental decision making.

Materials and methods

- Selection of the criteria that will have a direct influence on the facility in question. As can be expected, many different factors can be taken into account in spatial studies and those selected will be in accordance with the required objectives, the information available, planner's experience, etc. In the present study all the criteria (Table 1) are reflected in the corresponding GIS layers consulted from an extensive bibliography (Perpiña et al., 2012; Hubina and Ghribi, 2008; Gómez and Barredo, 2005; Munier, 2004; Bosque and Moreno, 2004). Experts were also consulted.

Table 1. Factors considered in siting a biomass plant.

Criteria	Description
Biomass resources	Spatial distribution of biomass in the region (t/ha) from land use maps.
Lithology	Lithological classification to determine industrial lithological capacity.
Nature Conservation	Classification of areas for conservation with the aim of conserving certain habitats.
Access by road	Identification of buffer zones for their proximity to different types of roads.
Economic development	Determination of the extent of economic development.
Operation costs	Determination of operation costs for biomass collection.
Slopes	The influence of slope as a constraint for this type of installation.

- Pairwise comparison matrices were used with AHP software in order to value the selected factors and their classes. To each criterion 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.

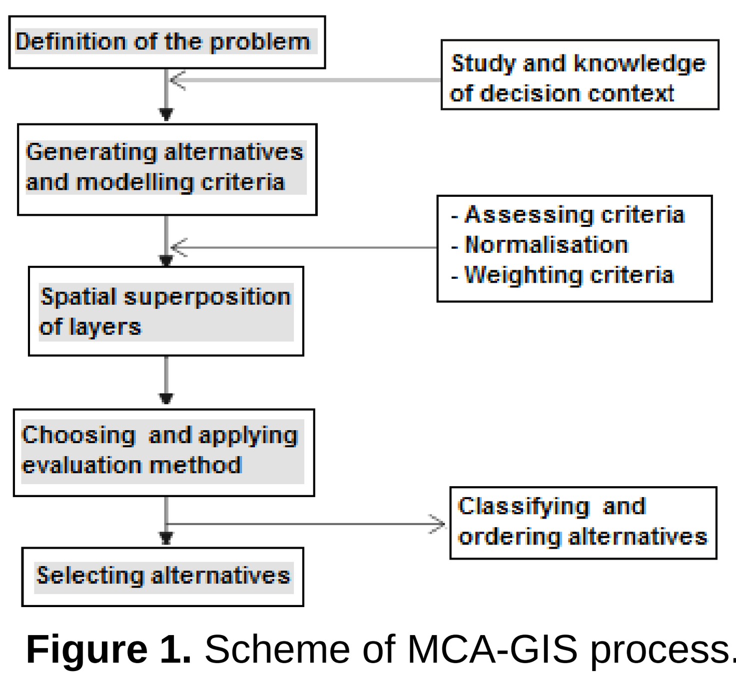

Figure 1. Scheme of MCA-GIS process.

- Before applying decision rules in a GIS environment, the cartographic information must be superimposed to integrate all the factors in a single layer and quantify the values of each alternative in order to reduce the possible number of plant sitting points. This process can be understood as adding together the spatial frontiers of the data in the case of polygonal entities, in which a set of polygons is obtained with the same homogeneous attributes as those of the factors from the previously established layers. After overlaying the spatial themes, the decision rule is applied to the simple objective and multiple criteria problem in order to obtain the alternatives map according to suitability.
- A sensitivity analysis of the results of the previous stage was carried out. This was done to determine the uncertainty level of the model predictions and input variables, with the aim of identifying the effect of factor and weight variations on the model results. This ensures the results are more reliable and identifies the factors by which they are significantly influenced.

Acknowledgements

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Results

Table 2. results of the pairwise comparison matrices.

Factors	Criteria	Weight w_{ij}
Environmental factors	Lithology	0.035
	Nature conservation	0.184
	Terrain slope	0.061
Economic factors	Access to roads	0.120
	Economic development	0.034
	Biomass quantity	0.283
	Operation costs	0.283

Granite substrate were the most valued in the **lithology** layer because of having the best physical properties for industrial activities (low permeability and high slope stability).

The slopes between 0% and 10% provided by the **slope** layer (Figure 3) were the most suitable areas in order to place a biomass plant due to their minimum morphological problems and lower economic costs.

With regards to the **economic development**, the class "High degree of local Economic Development" was the most valued. This class was calculated in function of a set of economic indicators for each municipality. In the case of **roads accessibility** layer, the areas where highways, roads and paths are less than 1 km away were the most valued. High density forest was the most valued class of the **biomass quantity** layer (Figure 4), since the spatial distribution of this resource greatly influences the final cost. In **operation costs** layer, Eucalyptus stands were the most valued because minimizes costs during the collecting tasks

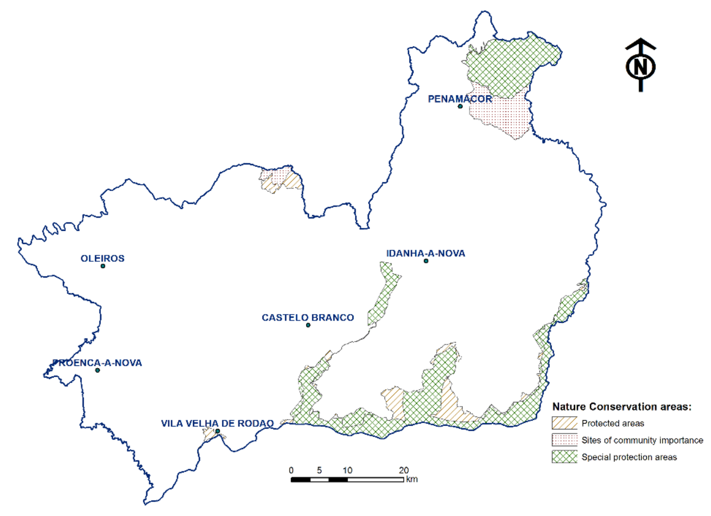

Figure 2. Nature Conservation areas.

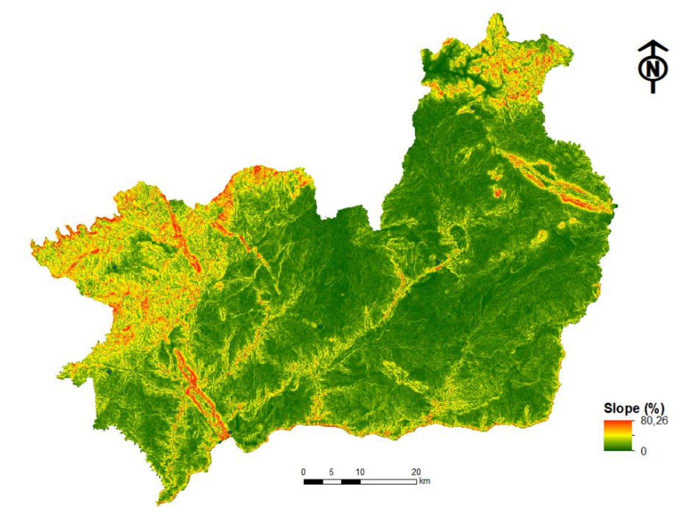

Figure 3. Slope.

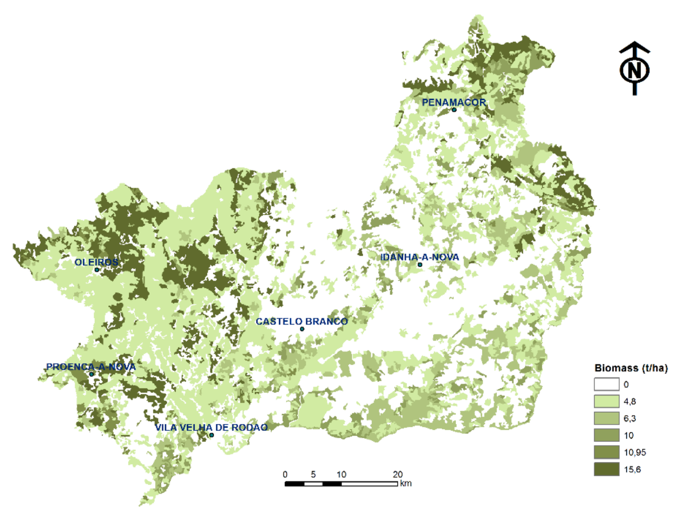

Figure 4. Biomass resources.

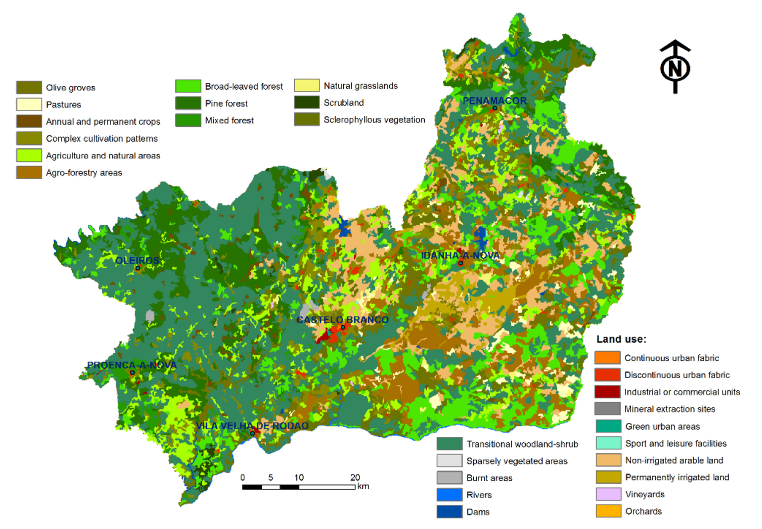

Figure 5. Land use.

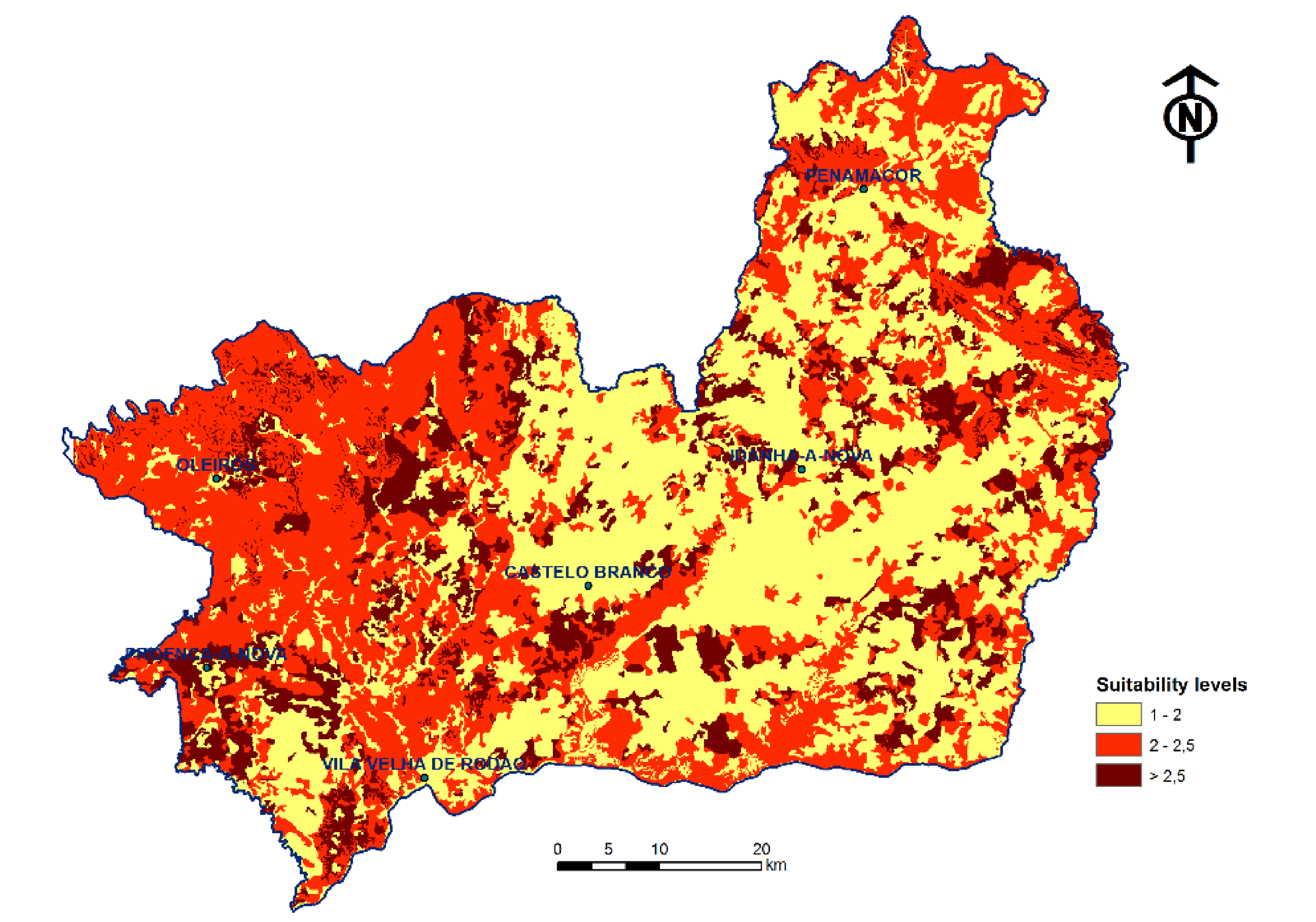

Figure 6. Suitability map for biomass plant location.

Conclusions

The combination of MCE and GIS methods can therefore be seen as a powerful tool for solving power planning problems, such as the location of biomass plants. MCDM techniques can be used to answer a range of different questions: it can firstly be used to obtain territorial information for planning power supplies, and secondly, it can provide the necessary tools to integrate this knowledge into the development of the project to support decision making and guarantee sustainable activities. For that purpose a last step must be develop in order to select the most suitable site for the biomass plant location within the areas with higher value.

The selection of evaluation criteria (weighted criteria) will have a considerable effect on the entire evaluation process and results can be skewed by including or excluding certain criteria. A scale between 1 and 9 was chosen to evaluate the criteria and pairwise comparison matrices were used to compare factors by Saaty's Analytic Hierarchy Process. A total of 7 factors were compared, including 3 environmental and 4 economic factors.

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