

# GIS-based suitability model for assessment of forest biomass energy potential in a region of Portugal

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**Abstract.** This work focuses on developed a decision support system based on multicriteria spatial analysis to assess the potential for generation of biomass residues from forestry sources in a region of Portugal (Beira Baixa). 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.

## 1. Introduction

Multicriteria decision analysis (MCDA) deals essentially with complex decisions that involve a large amount of information, a number of alternative outcomes and criteria to assess these outcomes. MCDA techniques can be used to identify a single preferred option, to rank options, to short-list a number of options for further investigation, or simply to distinguish acceptable from unacceptable alternatives [1]. Thus, multicriteria evaluation is used to solve spatial decision problems derived from multiple criteria. By integrating the evaluation techniques with GIS, the influential factor are evaluated and more accurate decision were taken [2].

The Analytic Hierarchy Process - AHP [3] is a multi-criteria tool considered to be relevant to nearly any ecosystem management application that requires the evaluation of multiple participants or complex decision-making processes are involved [4].

The Geographic Information System-based MCDA (GIS-MCDA) 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 [5-8]. One of the first multicriteria assessment studies in the context of

renewable energies, dealing with wind-generated electricity, was developed as a decision support system (DSS) to estimate the maximum obtainable generating potential [9]. Various studies were developed using GIS-MCDA techniques in the context of renewable energies [10-13]. In forestry was proposed a DSS for bioenergy applications in the form of a model that combines biomass production, conversion and electricity generation [14].

Recently was published a systematic review of multiple- criteria decision-making (MCDM) techniques and approaches in solving sustainable and renewable energy systems problems [15]. 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.

## 2. Materials and methods

### 2.1. The study area and data sources

The Beira Baixa region is an administrative division in eastern Portugal. The region covers an area of 4,614.6 km<sup>2</sup> and has a population of 84,046 inhabitants. The area includes four municipalities: Idanha-a-Nova, Penamacor, Vila Velha de Ródão and Castelo Branco. This territory is mainly occupied by forest and agroforestry uses (60.8 %) and agriculture (36.2 %).

The spatial data sets for the study were obtained from the following sources:

- National Statistics Institute (Agricultural and Population Census) (INE, 2015).
- Fifth level Corine Land Cover, European land occupation database (DGT, 2012).
- Sixth National Forestry Inventory (ICNF, 2013).
- Shuttle Radar Topography Mission (SRTM) - Digital Elevation Model (NASA and NSA, 2016).
- Lithological and geomorphological cartography (LNEG, 2014).
- Protected areas and Natura 2000 Network cartography (ICNF, 2017).

### 2.2. Spatial criteria selection

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 this study all the criteria (table 1) are reflected in the corresponding GIS layers consulted from an extensive bibliography [13, 16]. Experts were also consulted.

**Table 1.** Factors considered in siting a biomass plant.

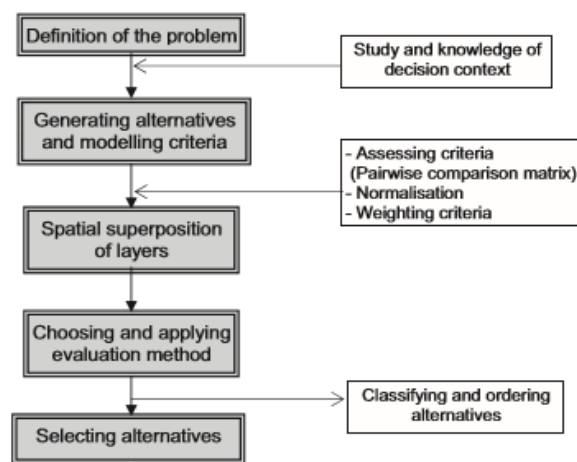
Criteria	Description
Biomass resources	Spatial distribution of biomass in the region (t/ha) from land use maps.
Lithology	Lithological classification to determine industrial lithological capacity.
Nature Conservation	Classification of areas for conservation with the aim of conserving certain habitats.
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.

### 2.3. AHP Pairwise comparison

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<sub>ij</sub> 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. Through a pairwise comparison matrix, the AHP calculates the weight value for each criterion ( $w_i$ ) by taking the eigenvector corresponding to the largest eigenvalue of the matrix, and then normalizing the sum of the components to a unity. It is necessary to verify the consistency of the matrix after obtaining the weight values.

The consistency is judged on the basis of a consistency ratio CR. The determination of CR value is critical. In our case study, we adopted a standard CR threshold value of 0.10 which has been widely used as a measure of the consistency in a set of judgments of AHP applications in literature. If  $CR < 0.10$ , it deems that the pairwise comparison matrix has acceptable consistency and the weight values calculated are valid and can be utilized.



**Figure 1.** Scheme of GIS-MCDA process.

Before applying decision rules in a GIS environment, the spatial data 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 data, 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 allowed 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.

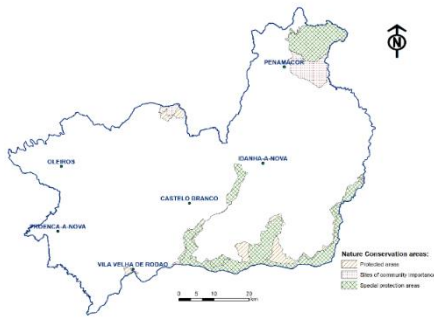
### 3. Results and discussion

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.

**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
Economical factors	Access to roads	0.120
	Economic development	0.034
	Biomass quantity	0.283
	Operation costs	0.283

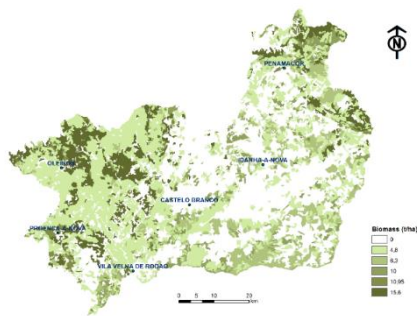
With regards to the economic development, the class “High degree of local Economic Development” was the most valued. This class was calculated in function of a set of economic indicators for each municipality. In the case of roads accessibility layer, the areas where highways, roads and paths are less 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.



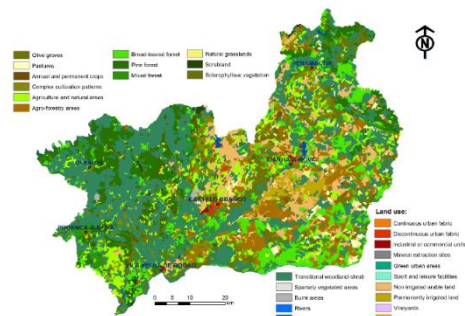
**Figure 2.** Nature Conservation areas.



**Figure 3.** Slope.

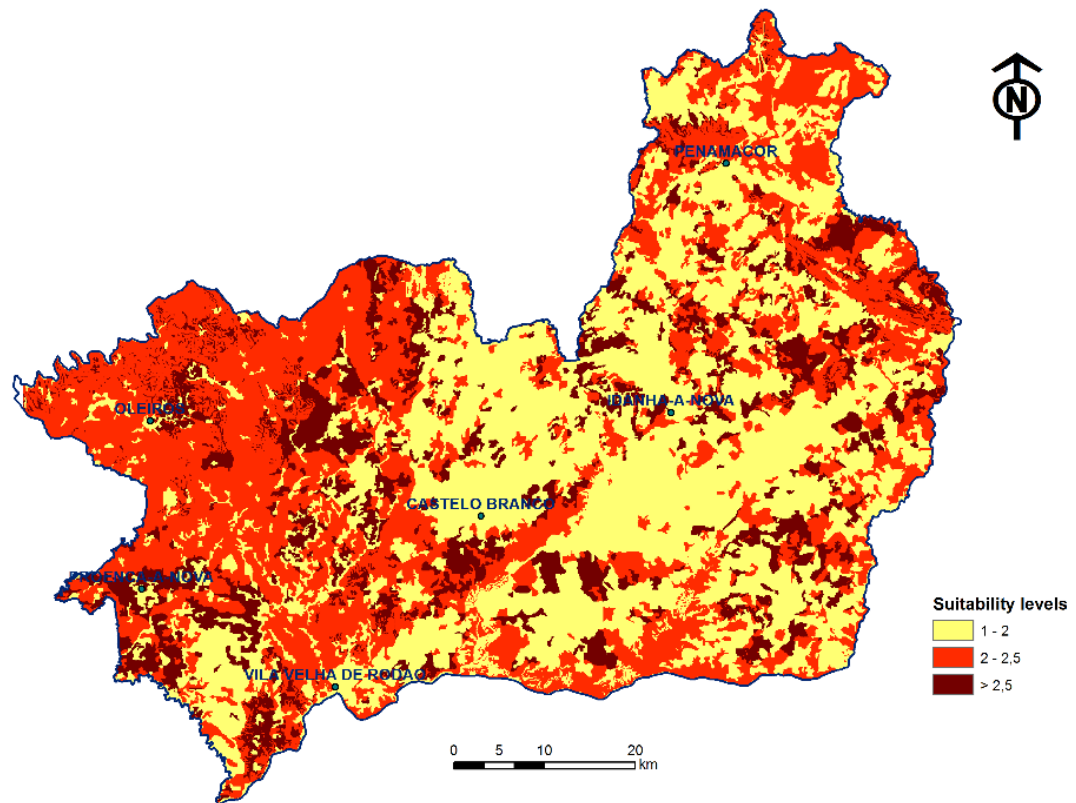


**Figure 4.** Biomass resources.



**Figure 5.** Land use.

Suitability map of Beira Baixa of the potential for generation of biomass residues from forestry sources using the weighted linear summation technique is presented in Figure 6.



**Figure 6.** Suitability map of the potential for generation of biomass residues.

#### 4. Conclusions

The combination of MCDA and GIS methods can therefore be seen as a powerful tool for solving power planning problems, such as the location of biomass plants. GIS-MCDA 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.

#### Acknowledgment(s)

This research was financially supported by the Geobiotec Research Unit (funded by the Portuguese Foundation for Science and Technology, through project PEst-OE/CTE/UI4035/2014, University of Aveiro, Portugal.

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