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Biogas plants site selection integrating Multicriteria Decision Aid methods and GIS techniques: A case study in a Portuguese region

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ABSTRACT

This work addresses the problem of determining the most suitable sites for locating biogas plants using dairy manure as feedstock, specifically in the Entre-Douro-e-Minho Region in Portugal. A Multicriteria Spatial Decision Support System is developed to tackle this complex multicriteria decision-making problem, involving constraints and many environmental, economic, safety, and social factors. The approach followed combines the use of a Geographic Information System (GIS) to manage and process spatial information with the flexibility of Multicriteria Decision Aid (MCDA) to assess factual information (e.g. soil type, slope, infrastructures) with more subjective information (e.g. expert opinion). The MCDA method used is ELECTRE TRI, an outranking-type method that yields a classification of the possible alternatives. The results of the performed analysis show that the use of ELECTRE TRI is suitable to address real-world problems of land suitability, leading towards a flexible and integrated assessment.

1. Introduction

Livestock farms produce excreta in large quantities, which traditionally have been used directly as manure to fertilize the land. However, in some cases, the disposal methods can cause environmental problems such as odour and water pollution [1]. There is growing interest in installing Anaerobic Digester (AD) to use dairy manure as a biomass resource for both economic value and environmental benefit [2,3]. An AD energy system promotes methane production, captures and converts it into electricity and heat, and also yields a fertilizer.

Biomass is part of Portugal's renewable primary sources, but in 2008 the relative contribution of Portuguese biogas for the biomass primary energy consumption did not reach 1% [4]. This factor together with the high biogas potential of Portugal shows that this important sector has been somewhat neglected [5].

To promote the development of dairy manure-based bioenergy systems it is essential to find suitable locations for

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such development [3]. Land-use suitability analysis is a tool used to identify the most suitable places for locating future land uses according to specific requirements, preferences, or predictors of some activity [6]. Determining suitable land for a particular use is a complex process involving multiple aspects that may relate to biophysical, socio-economic and technical aspects [3].

Choosing an appropriate location for a biogas plant is a task for which Geographic Information Systems (GIS) and Multicriteria Decision Aid (MCDA) are helpful [7–10]. MCDA provides significant support for the generation and comparison of alternatives taking into account the evaluation criteria through an active participation of experts and stakeholders involved in the decision-making process. MCDA offers as set of procedures, techniques and algorithms for structuring decision problems, and designing, evaluating and prioritizing decision alternatives [11,12]. Location problems have strong spatial dimensions, as a large number of spatial variables are involved, such as the proximity to rivers, roads or populations, and spatial characteristics of the region including geology, slope, and soil types among others. GIS are designed to store, manage, analyse and visualize geospatial data required by decision-making processes [13].

A large number of papers concerning multicriteria suitability analysis and GIS have been published (see Refs. [14–19]). More recently, GIS has been combined with MCDA in environment/ecology (e.g. Refs. [20,21]), in undesirable facilities location (e.g. Refs. [22–24]), energy ([25,26]), and location ([27,28]), among other application areas.

In this context, a specific family of Decision Support Systems (DSS) named Multicriteria Spatial Decision Support Systems (MC-SDSS) may provide effective support. MC-SDSS typically includes a set of geographically defined alternatives from which a choice, a ranking or a classification of a set of alternatives is made with respect to a given set of evaluation criteria [17].

In this paper, a spatial multicriteria approach for supporting decision-makers in the process of locating of biogas plants is proposed. Spatial multicriteria analysis requires information on the value of the criteria and geographical location of the alternatives, in addition to the preferences of decision makers. A variety of constraints, as well as economic, environmental and social factors are integrated in this approach to help determine the most suitable sites for installing such bio-energy systems. As an application of the approach proposed in this work, a land suitability map for locating biogas plants was developed for the Entre-Douro-e-Minho (EDM) region in Portugal. The result is a classification of each potential location into one of three categories of suitability: low, medium, or high suitability.

2. Methodology

The MC-SDSS developed for the present study is shown in Fig. 1, encompassing the three phases: intelligence, design and choice, according to the model proposed by Ref. [29]. In the intelligence phase, data is acquired, processed, and an exploratory data analysis is performed. This phase focuses on structuring the problem after which the objectives to pursue are explored and the evaluation criteria or attributes are selected. The design phase involves data collection and processing, as well as the development of multicriteria analysis through the definition of the relationships between objectives, attributes and preferences of the decision maker [12]. In this phase, specific decision rules are used to evaluate and sort alternatives. The choice phase usually involves formal MCDA-GIS interaction in order to develop a solution set of spatial decision alternatives, with integration of decision analytical techniques and GIS functions. In this phase, alternatives are evaluated in order to derive appropriate recommendations. This general framework for MC-SDSS development is based on the general architecture of spatial multicriteria decision-analysis from Ref. [12], but presents some changes in the Design Phase, such as the iterative application of the ELECTRE TRI to perform MCDA, and uses an innovative way to define the set of alternatives that are evaluated.

2.1. *Problem definition*

The EDM Region is located in the northwest of Portugal and consists of a set of 10 counties: Viana do Castelo, Barcelos, Esposende, Póvoa de Varzim, Vila Nova de Famalicão, Vila do Conde, Santo Tirso, Trofa, Maia and Matosinhos, with an area of 158,438 km^2. This region has 1705 dairy farms with more than 100,000 bovine animals, which produce approximately 1.5 million cubic metres of wastewater (solids and liquids) per year.

The dairy sector has significant economic and social importance to this region. However, this activity has generated numerous environmental problems linked to the high spatial concentration of farms and increasing number of animals, either caused by the volume of effluent generated and related impacts on water and soil, or by conflicts with urban areas. These factors, sometimes associated with insufficient storage capacity and sewage treatment, as well as the misuse of equipment and methods of spreading in the soil, result in contamination of crops and waterways, as well as production of unpleasant odours, among other problems.

As pressure from environmental regulations and surrounding community increases, it is important to build a set of ADs for a better manure management in this region. On the other hand, biogas plants belong to the group of undesirable facilities and are considered as NIMBY (not in my backyard) facilities, whose location presents two main problems to be addressed: (i) social opposition and (ii) a large number of social, economic and environmental data that have to be taken into account [30].

2.2. *Constraints and factors*

Recently, in Portugal, there has been a concern regarding the problem of evaluation of biogas production using different sources, but there is still no legislation defining the location, characteristics and limitations for installation of this type of plants. In this study, we resorted to Portuguese legislation directed to the installation of similar infrastructures (such as solid waste landfill), European legislation, other studies and the contribution of two experts – an agronomic engineer, specialized in the environmental field and GIS applications