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Research paper

Fuzzy spatial decision tool to rank suitable sites for allocation of bioenergy plants based on crop residue

Reynel Rodríguez, Paola Gauthier-Maradei*, Humberto Escalante

INTERFASE, Escuela de Ingeniería Química, Universidad Industrial de Santander, Carrera 27, Calle 9 Ciudad Universitaria, Bucaramanga, Colombia

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ABSTRACT

Agriculture crop residues represent one of the largest and most diversified sources for producing biofuel. However, these resources are highly heterogeneous in terms of the physicochemical properties, spatial distribution and logistics associated costs. These factors are the major bottlenecks hindering the success of biomass energy conversion facilities that use crop residues. The purpose of this study was to develop an integrated GIS-based Fuzzy AHP methodology. This approach combines both spatial and non-spatial factors, such as the logistics factor, transport cost indicators, and technical and geographic restrictions in the study area. The identification of these factors for the actors involved in energy planning provides at a broad-scale multidimensional analysis that allows for the identification of the best sites for a bioenergy plant. This methodology was applied in the department of Santander (Colombia) due to its intense agricultural activity, reflecting the important energy potential of biomass. For three cocoa crop residues evaluated (pruning, rejected and cocoa pod husk), it was possible to identify 12 ideal places to install a bioenergy plant using this approach. The capacity of these biomass plants varies between 52,475 and 146,791 t/year, corresponding to 171 and 479 TJ/year, respectively.

1. Introduction

Agricultural activity produces a large amount of biomass residues derived from cutting processes and conversion of the products of harvest into commodities for local and export markets, being commonly known as Agricultural Crop Residues and Agro-Industrial Wastes. These resources can be converted to bioenergy via different thermal, biological and physical processes. In the Netherlands, for example, a gasification process was fed by agricultural and forest residues as alternative energy sources, obtaining approximately 2,280 TJ/year of energy potential; its variation depended on the characteristics of each biomass [1]. In another study, tomato plant wastes were transformed into solid, liquid and gaseous fuels with higher calorific values: 26.0, 7.8 and 8.0 MJ/kg, respectively, using conventional pyrolysis [2]. Likewise, in Italy, the productivity potential of biogas that comes from the crop residue of rice, barley, grapes and corn was assessed, revealing an energy potential near 21,900 TJ/year via anaerobic digestion [3]. A similar case was documented in the province of Vojvodina (Republic of Serbia), in which the energy potential from post-harvest residues was estimated to be 12,600 TJ/year, leading to the construction of 79 plants that use the direct combustion of agricultural wastes [4].

Colombia is a country with extensive development in agricultural activity; it mainly generates wastes such as sugarcane bagasse, rice husk, coffee husk and oil palm empty fruit bunches [5]. These residues could be used to produce energy by means of an appropriated technology. Moreover, they could allow Colombia to introduce a new energy resource in the oil market, being very positive for the country, considering that, according to the recent statistics of oil reserves and fuel production, as well as the low rates of new oil well discovery, Colombia can face an energy emergency in the near future. The department of Santander is in northeastern Colombia (Fig. 1); it has an area of 30,537 km^2 and a population of approximately 2,010,404. Santander is, in the national context, one of the main agricultural regions. It can produce an outstanding diversity of crops, such as cacao, sugarcane, tobacco, oil palm, guava, pineapple and blackberry [6]. Consequently, agricultural residues are abundant and available any time of year. *Ministerio de Minas y Energía* has reported that the predicted availabilities of these resources are estimated to be approximately 2,153 Mt/year, corresponding to an energy potential of 15,400 TJ/year. Unfortunately, a large amount of this resource is burned or abandoned in

* Corresponding author.
E-mail address: mapaomar@uis.edu.co (P. Gauthier-Maradei).

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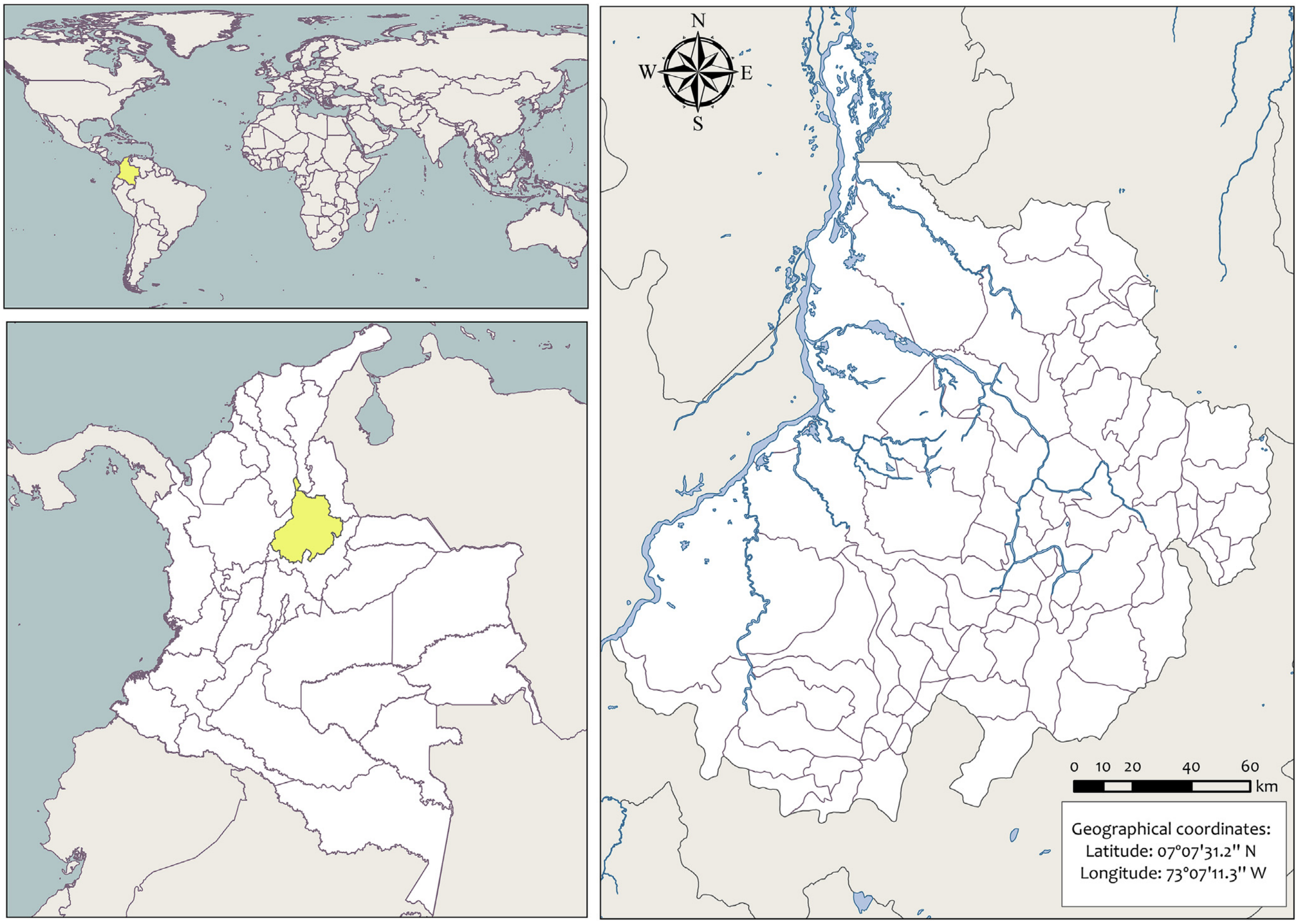

Fig. 1. Localization of the province (state) of Santander, Colombia.

farmland every year, which seriously pollutes the atmospheric environment [5].

In biomass planning, the great variability in the conditions of agricultural production makes it difficult to develop and generate a conceptually simple framework yet operationally useful roadmap for the sustainable use of crop residue. First, the physical conditions of agricultural production vary considerably from place to place. The types of commodities that can be produced, the type of resources used in production and the transformation rates of input into output vary correspondingly. Second, agricultural production normally occurs in an enormous number of independently managed small units. The operators differ in natural capacity, training and inclination for farming. Such intraregional variability influences the strategy of agricultural development and biomass potential role. Third, areas differ with respect to 1) endowment of natural resources and density of the population in relation to them, 2) technology levels, 3) the organization and economic structure of production, and 4) social, cultural, and educational patterns.

A systematic analysis of biomass potentials is an essential step toward their adoption as a safe, sustainable and competitive energy source. However, frequently in developing countries, the number of unanswered problems is so great and the gaps in statistical data and other information available are so apparent that there must be great consideration of the specific problems and gaps that demand immediate attention. These new challenges require tools that can identify and assess the environmental, social and economic aspects. The development of a Spatial Decision System Support (Spatial DSS) for the assessment of energy production that comes from biomass can help guide regional planners in the definition of potential bottlenecks or barriers and in the design of possible alternatives at the strategic planning level. Different techniques have been used as methodological approaches to provide a response to the question: where is the best site to localize a bioenergy plant? There are two main groups: the first uses Geographic Information Systems (GIS), while the last, mathematical programming methods.

Regarding the first group, the study performed for the Community of Valencia (Spain) is highlighted. It developed a methodology focused on logistics and transportation strategies to locate a bioenergy plant network based on agro-industrial and forestry residual biomasses. In its model, the optimization of transport costs was performed using a hypothetical transport network [7]. Likewise, specialists in the province of Alberta (Canada) carried out a feasibility study for the construction of 13 pellets plants, including a detailed study of the transport network and geographical restrictions. This last was represented by means of exclusion criteria and preference factors [8].

The second group includes mathematical programming approaches such as Mixed Integer Linear Programming (MILP) models; they have been frequently used as decision support and optimization methodologies in the selection of an ideal site of a bioenergy plant, capacity, and costs associated with the transportation of biomass [9]. However, the problem of selecting the best site for a plant has the complexity of multiple alternatives with often conflicting objectives, for which the multicriteria analysis