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A fuzzy information axiom based method to determine the optimal location for a biomass power plant: A case study in Aegean Region of Turkey

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ABSTRACT

Biomass energy is one of the fundamental renewable energy sources. It decreases fossil fuel combustion and consequently net greenhouse gas emissions since no new carbons aren't released to the atmosphere. Generally, agricultural, forest, animal and urban wastes are considered as potential sources for biomass energy. Among these sources, agricultural wastes are the most suitable type to generate biomass energy in Turkey. Aegean Region has a great potential with respect to its lands and its diversity of agricultural products. In this paper, the most appropriate location for a biomass power plant has been investigated among the eight alternative locations in Aegean Region by examining both quantitative and qualitative criteria. It is the first time, an integrated model including fuzzy sets, analytic hierarchy process, opinion aggregation method, and information axiom method has been proposed to obtain a solution for such a problem. According to the results, *Aydin* is determined as the most appropriate location for a biomass power plant at Aegean Region. Furthermore, a sensitivity analysis has been performed to present the reliability of the obtained results.

1. Introduction

Biomass is a fundamental renewable energy source and has various advantages such as decreasing greenhouse emissions through CO2 neutral conversion, utilization of inedible biomass, conservation of fossil fuels, and diversifying fuel supply and energy security [1]. According to the report of WBA (World Bioenergy Association), energy supply of the world is obtained from crude oil (32%), coal (29%), natural gas (21%), renewables (13%), and nuclear (5%), respectively. The amount of bioenergy use in renewable energy utilization is only 10% whereas the rest consists of hydro, solar, wind etc. [2]. In contrast to alternative energy sources like wind and solar energy, biomass energy has a great potential with its abilities to provide sustained energy. Furthermore, biomass is a strategic resource due to its features such as being applicable everywhere, good knowledge of production and conversion technology, being suitable for the energy production of all sizes, being able to be produced at normal temperature and low light intensity, being able to be used for the production of electrical, chemical compounds, and especially the fuel of internal combustion motor vehicles, being green energy source.

The energy consumption of Turkey has been increased year by year and the investments in energy production are lagging behind with respect to this increase. For instance, an increase from 3.041565 to 5.33197 EJ in total primary energy consumption in Turkey occurred between 2001 and 2012 whereas total primary energy production increased from 0.946335 to 1.456955 EJ [3]. Due to this difference between energy production and consumption, Turkey imports electric energy and energy sources such as natural gas and coal from abroad; and it makes Turkey dependent to other countries in terms of energy. However, Turkey has a great potential for renewable energy sources, in particular for biomass, and utilizing biomass effectively would reduce the energy dependency of Turkey. Several sources of biomass exist in Turkey; and among these sources, agricultural crops outperform municipal solid waste, animal manure, urban wastewater treatment sludge in terms of energy generation [3]. Biomass can be employed for several purposes such as electricity generation, providing heat for homes and industrial facilities and producing fuel for vehicles [4]. Furthermore, the total CO_2 emissions from energy consumption in Turkey gradually increased year by year [5]. It is thus possible to say that

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utilizing biomass effectively is extremely important for both economic and environmental reasons.

With rapidly growing and developing economy, making prospective investments has become an indispensable component for sustainability and efficiency of business firms. At this conjuncture, determining facility location is highly significant. The decisions which must be made before a facility is set up such as operational capacity, production management and their locations are vital for them. Facility capacity and requirements of production management directly affect the location decisions. The concept of location selection is based on specifying the location which brings the maximum benefit in the short or the long run with respect to various criteria that are determined in accordance with scope, capacity, production type, design, and planning of firm. Preferences for facility locations differ in line with characteristics, priorities, needs, objectives, and sectors of firms to be established. These preferences therefore affect facility location selection. Since the importance of location selection is well known, many studies and research have been conducted to determine the optimal places for biomass facilities. The purpose of this paper is to specify the optimal location for a biomass based facility in the Aegean Region of Turkey. Determining the optimal location among potential alternative locations is a multiple criteria decision-making problem including both quantitative and qualitative criteria. Since measuring qualitative criteria includes impreciseness or vagueness, the conventional approaches to a facility location problem tend to be less effective in dealing with this impreciseness or vagueness [6]. Therefore, in the scope of this paper, an integrated method including fuzzy sets theory, opinion aggregation method, and information axiom has developed and it is the first time, the method has been proposed to literature in order to handle location selection problem. While the fuzzy set theory proposed by Zadeh [7] has been utilized in order to cope with vagueness or uncertainty in human thinking process, information axiom has been employed to select the best alternative among a set of candidates. Moreover, fuzzy opinion aggregation method is added to calculation in order to combine experts' opinions, since there are multiple experts in the evaluation process and each expert presents his/her own opinion for each criterion.

The rest of this paper is organized as follows: Literature review on locating bioenergy facilities is given in Section 2. The employed method in this paper is described in Section 3. Section 4 presents the implementation of the proposed method for the Aegean Region. Finally, sensitivity analysis and conclusions are given in Sections V and VI, respectively.

2. Literature review

In the literature, several techniques have been utilized to handle location selection problem of biomass facilities. Among these, integration of MCDM (Multi Criteria Decision Making) methods and GIS (Geographic Information Systems) is one of the most preferred approaches. In the study of Silva et al. [8], ELECTRE TRI was used to divide alternative sites into categories as low, medium or high suitability. ELECTRE TRI was applied for both worse and best case scenarios, and whether or not a potential site falls into the same category for both of the scenarios was checked, and if not, further analysis was conducted by making a sub-division of these sites [8]. Sultana and Kumar [9] proposed a method in which potential plant locations, optimal sizes and number of plants were evaluated through a model in GIS. A land suitability model which takes several factors into consideration was formed and feasible locations for biomass plants were selected by employing AHP (Analytic Hierarchy Process) [9]. An integration of AHP and GIS followed by a logistics cost and greenhouse gas emission analysis [10] and an integration of the GIS, AHP (extended fuzzy logarithmic least squares AHP) and FWOD (Fuzzy Weighted Overlap Dominance) [11] were also employed to determine the optimal locations for a bioenergy facility. In the study of Perpiña et al. [12], in addition to the use of GIS, evaluation and weighting were performed through Saaty's analytic hierarchies. Weighted linear summation and ideal point method were used in order to attain the best alternatives. Finally, a sensitivity analysis was conducted by adopting the Soboli and the extended-FAST methods [12]. MCDM methods have been widely used to select the optimal location for the other renewable energy sources as well. The aim of Sánchez-Lozano et al. [13] was to determine the optimal site for a photovoltaic solar farm. A comparison between TOPSIS and ELECTRE TRI methods was made after the criteria weights were determined via AHP. AHP was preferred in this study because of its simplicity whereas TOPSIS and ELECTRE were chosen due to their different focuses. The TOPSIS method makes compensation of the lack or excesses in the criteria in a continuous manner, however, the ELECTRE TRI method works in a discreet manner [13]. In another study, Sánchez-Lozano et al. [14] used the combination of fuzzy AHP and fuzzy TOPSIS to select the best location for a wind farm. These methods were preferred because site selection problems involve many alternative sites, various qualitative and quantitative criteria. Moreover, these methods don't require expert assessment for each alternative and are effective when evaluation criteria aren't represented in the same units. Fuzzy AHP and fuzzy TOPSIS were utilized to derive the criteria weights and to assess the alternative sites, respectively [14]. Wu and Geng [15] aimed at determining the most suitable location for a solar–wind hybrid power station. AHP method was adopted to achieve this goal basically because of its practicability. Potić et al. [16] utilized AHP to determine the optimal location for the installation of solar panel power plant since AHP values experience and knowledge of people at least as much as the data used. Höfer et al. [17] preferred AHP to obtain reliable criteria weights in the process of wind farm siting, and it was indicated that it allows to identify the sites that are qualified as a combination of technical efficiency, economic feasibility, environment compatibility, and local social acceptance.

A significant amount of research has been devoted to specify the optimal locations of biomass facilities by using metaheuristic algorithms. Vera et al. aimed to find the optimal location for a biomass power plant, its size and supply area by using Binary Honey Bee Foraging (BHBF). The obtained results through BHBF were compared with the results from Binary Particle Swarm Optimization and Genetic Algorithms in order to attain the optimal plant size and location [18]. A Binary Particle Swarm Optimization (BPSO) technique was also employed to investigate the optimal location and supply area for an electric generation system which utilizes biomass. Then, the introduced technique was compared with genetic algorithms, and it was concluded that the proposed technique outperforms Genetic Algorithms [19]. Furthermore, Simulated Annealing, Tabu Search, Genetic Algorithms and Particle Swarm Optimization methods were employed and compared with each other to determine the optimal location of a biomass power plant. A BPSO technique which includes inertia weight factor to its structure was developed. The obtained results indicate that the developed BPSO provides better results than Genetic Algorithms and the other BPSO algorithms. It was also stated that Genetic Algorithms and Particle Swarm Optimization methods provide a better performance than Simulated Annealing and Tabu Search [20]. In the study of Bai et al., a lagrangian relaxation based heuristic algorithm was initially proposed, and then branch-and-bound structure was adopted to enhance optimality [21].

Apart from these approaches, mathematical programming has