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A GIS-based Multiple Criteria Decision Analysis approach for wind power plant site selection

Kazim Baris Atici [a,*], Ahmet Bahadir Simsek [a], Aydin Ulucan [a], Mustafa Umur Tosun [b]

[a] Department of Business Administration, Hacettepe University, 06800 Ankara, Turkey
[b] Department of Public Finance, Hacettepe University, 06800 Ankara, Turkey

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ABSTRACT

This paper deals with site selection problems for wind power plants and aims to propose a structural procedure for determining the most feasible sites. The application area is Western Turkey. The methodology is mainly composed of two stages: the first stage is pre-elimination of infeasible sites, and the second stage is evaluation of the available ones. Geographic Information Systems (GIS) are used to generate layers of data and to apply the elimination criteria and constraints. The alternative land areas are handled in terms of identical-sized grids, which are large enough to install one wind turbine each. Multiple Criteria Decision Analysis (MCDA) is then used to rank and sort the grids via the identified evaluation criteria. The problem is evaluated in 13 fields, which are a collection of several grids in order to evaluate larger scale areas to construct wind farms rather than for individual turbines. The evaluations are made both at grid (micro) and field (macro) levels and both deterministic and uncertain data are used. The results reveal a high level of consensus on the most feasible sites between the different MCDA methods applied. The proposed methodology provides a structured decision aid, which can be applied to other energy site selection problems.

1. Introduction

Turkey's geostrategic position of being located at the gateway between the East and the West makes it an important player in Eurasian energy affairs. As well as serving as an energy corridor, Turkey itself has been transformed into an energy-hungry country due to the increasing urban population, restructuring of the settlement areas and emerging industrialisation. This naturally brings out a need for new energy resources. Besides the new energy resources needs, Turkey is executing accession negotiations with the EU. The EU aims to get 20% of its energy from renewable energy sources by 2020. The energy resource shift from fossil fuels to the renewable energy sources will reduce Turkey's regulatory burdens in the accession period. More renewable energy will also enable Turkey to cut greenhouse emissions and make it less dependent on imported energy. Considering such an emerging market, which is not garnished with a large amount of hydrocarbon resources, the efficient use of renewables is much more important since there exists a vast potential of different types of such resources (wind, solar, geothermal, hydro and biomass) all over the land. Wind power is one of the most promising sources of energy especially in the Western part of Turkey. Recently, research efforts and support mechanisms have been growing in order to increase the share of wind-generated power in Turkish network sectors. There has been an increasing interest in installation of wind turbines in different regions by the private sector. By boosting wind power, Turkey will encourage technological innovation and employment. The *General Directorate of Renewable Energy* (organized under the *Turkish Ministry of Energy and Resources*) is responsible for engineering services for the investigation of potential resources and the licensing mechanism for the intended power stations is carried out by *Turkish Energy Market Regulatory Authority*.

Recently, the potential of wind energy in Turkey has been investigated and publicly reported by the *General Directorate of Renewable Energy* as a *Wind Energy Potential Atlas* (2007). The information presented in the report relies on measurements all over the country and deals with the technical factors to be considered in generating wind power such as the wind speed or the capacity factor. In the current setting, identification of a new wind power site depends on the application made by an entrepreneur in an

* Corresponding author.
E-mail addresses: kba@hacettepe.edu.tr (K.B. Atici), abahadirsimsek@hacettepe.edu.tr (A.B. Simsek), aulucan@hacettepe.edu.tr (A. Ulucan), utosun@hacettepe.edu.tr (M.U. Tosun).

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intended area, then evaluated by the authority as to if it can be licensed or not. Therefore, the process is application-specific and leans on the question of "*Can we install wind turbines in this area*?" With all the information available about the wind potential of different areas from the published official reports and geographical information from different resources, our motivation in this paper is to ask the question in a different way as "*Which areas are more suitable to install wind turbines?*"

The initial task before transforming this motivation to a structured methodology is to identify the different stakeholders and their preferences. Straightforward application of decision analysis techniques without a detailed stakeholder and preference investigation may lead to arguable and irrational results. The preferences may be contradictory, therefore any methodology modelling a real world case should look at the problem from different perspectives. Our aim is to deal with the wind power site selection problem, which involves different perspectives such as technical potential, financial feasibility or policies of regulatory authorities. One land area can possess a high wind power potential in technical terms; however, it may be impossible to construct a wind turbine in the given area since it might be declared as protected land by the governmental regulations, or it can be very distant from main roads that cause a very costly construction process. It is important to realize these contradicting perspectives to come up with a robust identification of feasible land areas satisfying the preferences of different stakeholders of wind power plants.

In this paper, we mainly benefit from two decision-aiding tools in order to handle this multi-dimensional problem: *Geographic Information Systems* (GIS) and *Multiple Criteria Decision Analysis* (MCDA). MCDA techniques are well known to enable the integration of the different decision maker preferences. In this manner, they can be beneficial to cope with the above mentioned contradictions in the wind site decision process. Of course, before deciding on the most feasible areas, it is important to identify the alternatives. GIS play the important role of data generation and unsuitable alternative elimination. We analyse a specific region with the highest wind energy potential in Turkey, and it consists of two districts in the Western part of the country (Balıkesir and Çanakkale). We design a step-by-step process that initially eliminates the infeasible or unsuitable areas and then, ranks or sorts the remaining sites relying on multiple criteria. Although the methodology seems too technical, it produces important policy implications for different parties, which are also discussed throughout the paper.

In the literature, GIS-based approaches have been used in Renewable Energy Systems (RES) planning and decisions, which include wind farm siting. Recent examples include Lejeune and Feltz (2008), Aydin et al. (2010), Tegou et al. (2010), Haaren and Fthenakis (2011), Phuangpornpitak and Tia (2011), Sliz-Szkliniarz and Vogt (2011), Zhou et al. (2011), Al-Yahyai et al. (2012), Grassi et al. (2012), Ouammi et al. (2012) and Gass et al. (2013). The studies mostly focused on identifying the most appropriate land areas for installation of wind turbines and developed several criteria relying on different sources, which can lead to a robust selection process. It is very often that the decision-making process is supported with the use of MCDA methods.

The current paper contributes to the literature in several ways. We follow a two-stage methodology in the selected region: elimination and evaluation. We integrate two approaches (GIS and MCDA) in order to propose a structural procedure for the site selection problem for wind turbines. GIS serves as an elimination and data generation tool and feeds the evaluation stage. In order to be robust about the elimination, we create layers of data and keep it as rich as possible so that the remaining land areas are totally feasible to consider. Here, we contribute to the site selection problem with a wide literature research to identify the elimination constraints. After a tight elimination, we have several land alternatives to evaluate, and their data are generated in the GIS. In the evaluation stage (which is a multiple criteria decision problem), we handle the alternative areas with a novel gridding approach, where each grid is technically and legally large enough to construct one turbine. We provide three different perspectives via application of three contemporary MCDA techniques for ranking and sorting purposes. Our evaluations are both at micro and macro levels, which means we have results for both for the grids and collection of grids (fields). At the micro level, we work with deterministic data for each grid. We rank and sort alternative grids using *Elimination and Choice Translating Reality* (*ELECTRE*) methods (ELECTRE III for ranking, ELECTRE-TRI for sorting). At the macro level, we work with collections of grids (fields) as alternatives. The idea of fields is important because it enables us to evaluate neighbouring land areas for multiple turbines. The motivation behind this is that no investor would search for an area to install only one turbine. Therefore, a selected site's performance is not only underlies its individual performance but also its neighbour grid's performance. The data for a field are the collection of deterministic data forming the given field, so the data becomes bounded. Therefore, in order to perform analysis at the field level, we also have to deal with uncertain data. The Stochastic *Multiobjective Acceptability Analysis (SMAA)* method is used for analysing the field level data. The results are presented at the field level, and they reveal a consistency between different methods applied and highlight a number of fields as highly ranked or of a top category.

The paper is organised as follows: Section 2 provides brief information about Geographic Information Systems. In Section 3, we present the methodological considerations of three Multiple Criteria Decision Analysis methods; ELECTRE III, ELECTRE-TRI and SMAA-TRI, respectively. Section 4 is the methodology and data section, where our step-by-step approach, data generation and analysis framework are explained in detail. Section 5 discusses the results of multiple criteria analysis and Section 6 provides the policy implications and limitations of the proposed methodology. Section 7 concludes. The graphical material (maps generated in GIS) are provided in the Appendix.

2. Geographic Information Systems (GIS)

A Geographic Information System (*GIS*) can be defined in basic terms as '*a computer system that can hold and use data describing places on the Earth's surface*' (Rhind, 1989). It is a geographic data acquisition and a decision aiding tool with a widespread use in different areas such as urban management, transport planning, environmental management, telecommunication, service planning, national defence, network management or marketing (Heywood, 2010; Rolf, 2001). As a result of this wide scope of use, the definition of the concept can differ depending on who is using it for what purpose. In broader terms, we can define a GIS '*as a system of hardware*, *software*, *and procedures to facilitate the acquisition*, *management*, *manipulation*, *analysis*, *modelling*, *representation*, *and output of spatially referenced data to solve complex planning and management problems*' (Carrion et al., 2008; Tegou et al., 2010).

The primary purpose of a GIS is maintaining data about geographic space (Rolf, 2001). It allows geographic data to be organised, to be integrated with other data and to be analysed resulting in creation of new data and useful information in decision-making. One of the fundamental features of a GIS is *data layers* representing different characteristics in a given area. It enables creating specific criteria for each layer and overlaps all the layers so that the optimum area satisfying all criteria can be generated. Therefore, it is widely used in site selection problems for different purposes. In general, site selection via GIS follows the steps of *identifying relevant factors*, *collecting data*, *identifying the siting criteria*, *overlaying* and