Renewable and Sustainable Energy Reviews 76 (2017) 425–433

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Challenges in the wind turbines location process in Central Europe – The use of spatial decision support systems

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ARTICLE INFO

Keywords:
Wind turbine
Spatial decision support system
Renewable energy location
Spatial econometrics

ABSTRACT

The implementation of a framework for climate and energy policies in Europe entails a number of development projects connected to renewable energy resources. As far as many Western countries have realized some of those investments during recent decades and have more experience in that field, most of the countries in Central Europe have to face that challenge right now. However, a rapid increase in renewable energy production in those countries can cause some dysfunctions in the investment process. National control authorities in Poland marked that the decision-making process concerning the location of wind turbines has not been carried out properly. The paper presents a review of the studies regarding the use of spatial analysis in renewable energy policy implementation and a proposition for the use of the multi-criteria spatial decision support system based on Geographical Information Systems. The presented model has a character of an open framework which allows a user to add any location parameter or factor which is possible to be represented as a metric value. The spatial character of the proposed solution exceeds only mathematical models in the way of interpretation of the results. An intuitive model supports communication with stakeholders and helps to explain the correlations between human activity and the location of power plants. The model was tested on the case study of Wrocław agglomeration area (Poland) and includes 13 location factors. The use of a multi-criteria model guaranteed a broader point of view in comparing five different scenarios of wind farms development in the decision-making process, as it combines conflicted interests groups, minimalizes subjective assessment and enables to define priorities while setting weights of factors.

1. Introduction

The implementation of the Climate and Energy Package in Europe has a significant influence on the economy. Reaching the goals to increase the share of renewable energy to at least 20% by 2020 [1] and 27% by 2030 [2] entails a number of development projects. Many countries in Western Europe have realized some of those investments during the last decades. Countries like Sweden, Finland, Austria, Denmark and Portugal have already reached - or are really close to reaching - the European targets set for 2030 [3]. These countries have gained vast experience in the field of implementing renewable energy systems in comparison with, for instance, the Czech Republic, Slovakia, Hungary or Poland. The cooperation between Western countries that has lasted for many years allowed the dissemination and exchange of this knowledge. Most of the Central European countries currently face the problem of a rapid increase in demand within the renewable energy sector. However, the need of sudden changes in the energy sector in those countries can cause some dysfunctions in the investment process, like impropriate locations, used technology or size of investments. Therefore, the aim of this study was to provide an overview of the possibility of using SDSS while choosing the optimal wind turbines location due to various factors in Central Europe conditions.

Poland, being the largest new Member State of the European Union in Central Europe, is the country which was selected by the authors to make an analysis of the process of investment in renewable energy resources, in particular, wind energy systems. To date, most of Poland's energy still comes from fossil fuels, coal in particular. Aside from biomass co-firing, more than half of the renewable energy produced in Poland comes from wind, which makes it the most significant renewable resource in the country [4]. It is congruous with the European situation, in which wind energy is also one of the most important and growing components of the renewable energy supply [3].

Besides increasing the share of renewable energy, Poland has to invest in the development of energy systems by 2030 in order to increase the national energy production and keep up with its domestic demand. It should be noted that according to the prognosis of the

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http://dx.doi.org/10.1016/j.rser.2017.03.039
Received 14 December 2015; Received in revised form 16 February 2017; Accepted 8 March 2017

Polish Ministry of Economy, energy needs will increase by 21% until 2030. The largest increase in the national energy demand is expected after 2020, which is due to a higher projected growth of the gross domestic product and the inclusion of nuclear power plants with a lower efficiency of electricity generation than coal-fired sources into the existing energy system [5]. Taking into consideration that the realization of projects which deal with energy production is usually time-consuming, both because of administrative procedures as well as technical development, there is an urgent need to take further steps to build new installations which improve the current Polish energy system.

2. Methodology

The objective of this paper is to provide an overview of the possibilities of the implementation of new information technology (IT) tools in the decision-making process about the location of wind turbines. As location decisions rely on many factors, the multiple criteria decision making approach is becoming popular in the field of energy planning due to the flexibility it provides [6]. For this purpose, Spatial Decision Support Systems (SDSS) were analysed. The framework should allow the determination of various spatial location factors and their weights separately in the first step. The suitability of analysed locations should be the final information to avoid manipulations while the model is used. Moreover, the model should combine economic as well as social and environmental factors. The test area for a model was the Wrocław agglomeration, located in the Lower Silesia region in South-West Poland. This area creates a functional zone defined by the European Environment Agency in the framework of the Urban Atlas project [7]. In the case of Wrocław, the area stretches over 4500 km^2. As a result of the review of spatial policies developed by Polish municipalities, the model allows to compare five different locations of wind turbines as separate scenarios of future development.

The concept of the research implies the revision of the location factors of wind turbines, including the component of the social, economic and environmental contexts in order to create a matrix of indicators that should be taken into account in the decision making process. For each necessary factor, spatial data characterizing the local conditions were collected. All these data allow for the building of an optimization model for choosing the best wind turbines location, taking into account the multi-factorial nature of the decision-making process. The step of the allocation of weights for each factor is a field of uncertainty in the optimization model. This ascription cannot be arbitrarily and globally established for the whole model as different factors might be used and assessed according to local conditions. Hence, assigning weights will be presented for illustrative purposes only. The model has to be compatible with common GIS (Geographical Information Systems) software so that local authorities would be able to use it. For this purpose, the ArcGIS software was chosen [8]. The framework for the dynamic decision-making process was created in its extension, the CommunityViz tool [9]. The GIS software is currently a popular tool for the potential assessment of a variety of kinds of renewable energy including hydro power [10,11], tidal energy [12], solar [13], geothermal [14] or wind energy [15,16].

The data are presented and structured as follows. First an overview is given of the location conditions for wind turbines in Poland; second, an overview is presented of Spatial Decision Support Systems; and third the concept of a multifactor spatial decision support model for wind turbine location is given. The paper ends with conclusions and recommendations.

3. Wind turbine location conditions in Poland

Due to the Energy Union Package [17] and its impact on increasing the share of renewable energy in the total energy mix, Poland is developing projects in the field of renewable resources. Depending on the local conditions for each region, a different type of installation can be dominant. In the case of wind energy, the most preferred locations can be found in the regions stretching along the Baltic coast and around the north-east border of the country (energy zone I – extremely beneficial) (Fig. 1). The highly beneficial energy zone II covers an area located south from energy zone I and stretches from the German border to the capital of Poland – Warsaw, in the latitudinal belt across central Poland. The south part of the country is characterized by less favourable conditions, however, wind turbines were erected in those parts of Poland, as well. The case study area is classified as the III and IV energy zone, according to the classification published by the Institute of Meteorology and Water Management [18].

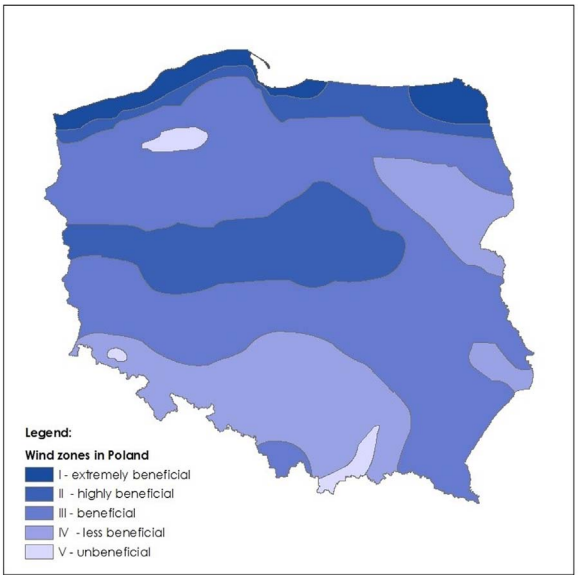

Fig. 1. Wind zones in Poland.

An analysis of the wind energy zones developed for the whole country need to be expanded locally and should be related to, for instance, local studies with the prevailing wind direction in order to choose the most suitable location on a more detailed scale. These tests enable the proper orientation of wind turbines, and the optimization of profits arising from the installation [19–21]. Similar tests have been carried out in Lower Silesia, too. The most optimal solution, in the case of energy zone III – beneficial, is to orient the turbines in the south-west direction (west measurement point), the west direction (central measurement point) and north-west (east measurement point). However, it should be noted that wind energy potential is changeable and can vary depending on a month or season of a year [22] or on the global climate conditions which may influence the availability of wind [23].

All the aforementioned factors are approximate and the data are characterized by a high degree of generalization. The goal of their presentation is to describe a background for the environmental conditions of wind turbines location. The proper choice of a location requires a more detailed analysis and assessment of many features in local terms [24–26]. These elements are deliberately omitted at this stage as they are presented in Section 4.

However, regardless of any natural conditions, a key element in the implementation of wind turbines is their compatibility with the legal framework. The local act of law that regulates the possibility of locating such facilities is a master plan, which is a precise document which describes the many technical parameters of the planned investments. Each master plan must, however, be consistent with a more generalized document – the spatial policy of each municipality. A spatial policy describes the general trends and factors which should be taken into account when preparing a master plan. Therefore, both documents are fundamental and they are prepared by local authorities that will