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Original Research Article

Multi-criteria decision support system for wind farm site selection using GIS

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ABSTRACT

The present study analyzed a multi-criteria decision support system to define wind energy resources in western Iran. Clean domestic renewable energy can be the best option in consideration of intense economic development and its accompanying increase in energy consumption. The most important barrier to wider deployment of renewable resources in Iran is the price of fossil fuels, which is the lowest in the world. The government has recently decided to remove subsidies for fossil fuel, meaning that its price will increase and will make the cost of green energies more attractive.

Wind power is an option for improved economic conditions in the region and low environmental impacts. This study applied geographic information system to determine the potential of wind energy in Markazi province in western Iran. The multiple criteria decision making method and site selection criterion for wind resources assessment is explained and developed for the study area. Criteria of equal importance were investigated, including technical, environmental, economic and geographic standards. The results were favorable for electricity production in accordance with international standards from wind in western Iran. The results show that 28% of the study area has capacity for installing large wind farms.

Introduction

Energy is the driving force behind economic development and industrialization around the world. Fossil fuels are currently the primary accessible resources that supply the world's increasing energy demands; however, fossil fuel reserves are limited and their usage has significant environmental effects. Since the first oil crisis, renewable energy sources have been a focus of study because they are renewable, sustainable, and environmentally friendly. Renewable energy sources for electricity production continued to improve and are gradually replacing fossil fuel-based power plants. There is increased public awareness of the negative environmental impact of conventional power generation methods, especially coal and oil fired power stations.

Wind energy is currently one of the most significant renewable energy resources; it is a fast growing, commonly used, and commercially attractive source to generate electricity because of its mature and cost-effective energy conversion technology. The cost of electricity generation from the wind energy has become competitive with power from fossil fuel plants.

The wind energy is expected to play a major role in fulfilling recent targets set by national policy in Iran. This kind of energy is attractive for planners and developers due to its low economic, environmental and social costs because it minimizes dependency on fossil fuels, and can rapidly improve the quality of life in remote areas. Because it is a clean and renewable energy source and addresses increasing global concerns about climate change and energy supply.

Wind energy is perceived to have some negative environmental impacts too, which should be systematically addressed using spatial policy instruments to ensure that it is in harmony with national policies on infrastructure, ecological, and socio-economic systems. Identifying suitable areas for wind farm using integrated results of surveys and studies is complex and requires decision-making that is subject to human error. Geographical Information Systems (GIS) can help to minimize these errors by identifying prospective areas using a combination of digital thematic maps [1–3] and a conceptual model for data integration.

The selection of the wind farm sites is the most important decision in the development of a wind farm. It is the best accomplished by listing the criterion affecting the environment, economics and viability of wind energy output over production time. Selection

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must take into account technical, environmental, and economical restrictions.

Suitability site selection for wind farms is one of the major technical challenges on wind resources development [4]. Wind farm development requires large initial investments; for example, the cost for a wind farm built in Ainsworth, Nebraska in 2005 was around 81 million U.S. dollars [5]. Thus, defining proper location for wind farm is critical for the economic viability.

In recent years GIS have been widely used as a decision support system (DSS) to assist in locating suitable sites for wind farms [4,6,7]. GIS as a DSS affords the functionalities of integrating a large amount of geospatial data into the decision-making of wind resources evaluation and development. A number of DSS methods and techniques have been applied to conduct site selection process for wind farm [4,6,8,9].

Rodman and Meentemeyer employed a rules-based GIS modeling approach to assess the suitability of wind farms in Northern California, U.S., in which effective factors were grouped into three categories (physical, environmental and socio-economic) [4].

A group of technical, economic and policy factors were incorporated into a GIS tool to define the locations for wind farms in Iowa, U.S. [10]. A similar approach was adopted to locate available areas for installing wind turbines in southwestern Taiwan [11].

Baban and Parry defined and applied 14 criterion such as slope, historical and memorial sites, land use and etc. to find suitable locations. They applied a weighted overlay analysis using GIS to define potentially suitable sites for wind farms in the United Kingdom [6].

Janke used multi-criteria decision making GIS modeling technique to define the potential locations for wind farms in Colorado State. Janke applied different factors, including distance to roads and cities, wind potential and population density, were garnered from available geospatial databases, converted to a raster data structure and overlaid to produce a wind development suitability map for northeastern Colorado [9].

Haaren and Fthenakis conducted a study in the State of New York, U.S. and applied more new ecological and economic criterion to the Janke's factors, such as the avoidance of avian impacts and economic costs to the wind development [7].

This study used also geographic information system to determine the potential for wind energy resources in Markazi province in western Iran. Criterion of equal importance were investigated, including technical, environmental, economic and physiographic standards. In this paper criterion divided into two parts containing restrictive and classifying layers. The results were favorable for electricity production in accordance with international standards from wind in western Iran. The main difference of the paper form previous research is computation of data layers in two different integration algorithms. It can be increased the accuracy of the site selection.

Wind energy in Iran

Iran began to explore renewable energy sources a decade ago and they are still in initial stages of development. Wind turbines were first used in 1994, when two sets of 500 kW wind turbines were installed in the areas of Manjil and Roodbar in northern Iran. The average wind speed in the area was 15 m/s for 3700 h/yr in Roodbar, and 13 m/s for 3400 h/yr in Manjil [12,13]. There are currently 111 wind turbines in Manjil and Roodbar with a total capacity of 61 MW.

Another large wind farm is installed in the Binaloud mountain region in Khorasan province, northeastern Iran. The area is a natural wind tunnel with 50 km in length and 5 km in width through which the wind steadily flows at a mild velocity of 8.9 m/s [12–14]. The wind farm operates 45 wind turbines (each 660 kW) with a total capacity of 28.6 MW. All of the wind turbines (V47–660 kW) were manufactured domestically. Other wind turbines similar above have been installed in Zabol area in Southeastern, Shiraz in central, Tabriz in Northwestern, Takestan in western, and Mahshahr in Southern Iran.

In 2014, Iran generated 126 MW of electricity from the 162 wind turbines in the country [13–17]. In 2008, the wind power plants in Manjil and Binaloud produced 82 MW of electricity. By 2009, a wind power capacity of 91 MW was reported for the entire country, which increased to 94 MW by February of 2012 [15]. A country wind atlas project estimates that, according to available wind power generation technology, economic conditions and wind potential, the power generation potential in Iran is about 15,000 MW [12,13,18].

A supportive law was passed in 2008 that obligates power production and distribution companies to buy electricity produced from renewable energy resources. The government has also recently approved an increase on the purchase tariff for the electricity generated by renewable energies from about 1330 Iran Rials (4.4 USD Cents) per kWh to more than triple to 5660 Rials (17.6 USD Cents) per kWh. In addition, during last few years, Iranian Ministry of Energy has made strides toward developing the legal and financial infrastructures required for the growth of wind power sector [19–21].

Advances in construction of wind turbines has decreased the cost of this form of electricity production and made it one of the most suitable renewable energy resources. Geographically, Iran is crisscrossed by some of the earth's main wind currents. The Ministry of Energy has initiated projects to manage and supervise renewable energies. Major projects include those for the Manjil, Paskulan, Rudbar, Harzovil, Siyahpush, and Binalud wind power plants. Article 135 of the 5th Five-Year Economic Development Plan (2010–2015) also obligates industry to increase power generation from wind energy and solar power plants to 5000 MW by the end of 2015.

Analysis of the technical potential of the country indicates that the current electricity demand of Iran (75,000 MW) could be provided solely by wind energy if network access, transmission, distribution and electricity storage by hydro power plants allow for such technical approaches [22]. Fig. 1 show Iranian wind speed map at 80 m height.

Study area

Markazi province is located in western Iran and has been investigated for the availability of wind energy potential. The capital of the province, Arak, is located at 34°37′27″ north latitude and 49°59′11″ east longitude. It has an area of 29,530 km^2 (1.8% the area of the country) and has a population of 1.41 million (2012). Topographically, 33.91% of the province area is mountainous, 14.93% is hilly, 13.76% is a plateau, and the rest is plains. The province comprises 10 counties, 18 districts, 27 cities, 61 rural districts and 1639 inhabited and uninhabited villages [23].

The difference in elevation from the lowest point (Saveh plain at 950 m in elevation) and the highest point (Shahbaz summit at 3388 m) is about 2400 m. This difference is the root of the diversity of climate and weather [23] and is a positive factor for wind generation development. Annual mean precipitation is 170 mm in Saveh plain and 450 mm in the highlands of the southeastern areas at 2000 m in elevation. The mean annual temperature ranges from 18 °C in Saveh plain to 4 °C in highlands.

In recent decades, the expansion of the north-south railroad (commonly known as the Persian corridor) and construction of major factories and large industrial complexes for metal, textile,