Applied Energy 96 (2012) 292–301

Contents lists available at SciVerse ScienceDirect

Applied Energy

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

Adapting a GIS-based multicriteria decision analysis approach for evaluating new power generating sites

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ARTICLE INFO

Article history:
Received 12 July 2011
Received in revised form 2 November 2011
Accepted 30 November 2011
Available online 27 December 2011

Keywords:
Clean and low-carbon energy
Energy policy
Multicriteria assessment
Spatial analysis
Energy generation
Geographic information system

ABSTRACT

There is a growing need to site new power generating plants that use cleaner energy sources due to increased regulations on air and water pollution and a sociopolitical desire to develop more clean energy sources. To assist utility and energy companies as well as policy-makers in evaluating potential areas for siting new plants in the contiguous United States, an adaptation of a geographic information system (GIS)-based multicriteria decision analysis approach is presented in this paper. The presented approach has led to the development of the Oak Ridge Siting Analysis for power Generation Expansion (OR-SAGE) tool. The tool takes inputs such as population growth, water availability, environmental indicators, and tectonic and geological hazards to provide an in-depth analysis for siting options. To the utility and energy companies, the tool can quickly and effectively provide feedback on land suitability based on technology specific inputs. However, the tool does not replace the required detailed evaluation of candidate sites. To the policy-makers, the tool provides the ability to analyze the impacts of future energy technology while balancing competing resource use.

1. Introduction

As the need to expand our energy supply in the 21st century grows, so does the need to ensure that new energy technologies provide reliable sources of energy that protect national security, environment, and overall economy. The growing environmental costs of fossil fuels have placed an emphasis on siting energy generation technologies in a manner that minimizes impacts on the environment. Over the past decade there has been a trend to move away from the traditional fossil fuel sources without much success [1]. In the 2011 State of the Union address, President Obama announced a national clean energy standard goal of 80% clean energy by 2035. This recent political push for a clean energy policy has created a never before seen mandate for the energy sector to balance electricity demand with the deployment of new diversified generation of clean and low-carbon technologies. For the rest of this paper, the phrase "clean energy" includes low-carbon energy sources such as nuclear. A clean energy standard would create a free market under which these technologies would compete with each other. The clean energy sources being considered are wind, solar, hydro, geothermal, biomass, natural gas, and coal with carbon capture and sequestration; other energy sources are low-carbon options such as nuclear. As a result of this mandate, the United States may need to site hundreds of new power generating plants to achieve the goal of generating 80% of the country's electricity from clean/low-carbon energy sources by 2035 [2]. The question being asked then by utility and energy companies and even policy-makers is "Does the United States have enough land area (close to energy resources) to site hundreds of new generating plants?"

To help answer this question, an adaptation of a geographic information system (GIS)-based multicriteria decision analysis (MCDA) approach is proposed for siting new generating plants on a national scale. A GIS-based MCDA approach is used to screen the contiguous United States by dividing the land area into millions of 100 m by 100 m (or approximately 2.5 acres) gridded cells to determine site suitability. The focus of the methodology is identifying candidate areas for multiple power generation technologies. This approach is designed to quickly screen for and characterize candidate areas based on multiple criteria. These criteria range from environmental constraints to physical geological constraints

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0306-2619/$ - see front matter Published by Elsevier Ltd.
doi:10.1016/j.apenergy.2011.11.087

to socioeconomic constraints. The proposed approach has led to the development of the Oak Ridge Siting Analysis for power Generation Expansion (OR-SAGE) tool at the Oak Ridge National Laboratory (ORNL). The approach that drives the tool utilizes about 30 geographic datasets that are directly related to the construction of new energy generation technology. The tool can model multiple scenarios ranging from policy implications to technological advancements and the impacts that these new plants would have on local, state, regional, and national resources. The proposed approach has been applied to three energy generation options and one energy storage option – nuclear (RX), concentrated solar (CS), advanced coal technologies with carbon capture and sequestration (CCS), and compressed air energy storage (CAES).

An MCDA is a process of assigning values to alternatives that are evaluated along multicriteria. There are many methods and procedures, such as Analytical Hierarchy Process (AHP), for handling multicriteria decision making. Traditionally, multicriteria decision making techniques have largely been aspatial, that is, assumption of homogeneity within a study area [3]. The integration of geographic information system (GIS) and multicriteria decision analysis has attracted significant interest among urban planners since the 1990s. According to Malczewski [4], the GIS-MCDA approaches are most often used for tackling land suitability problems, and they are frequently used in application domains such as waste management, forestry, natural hazard management, agriculture, and ecology and environment. A GIS-based multicriteria decision analysis has recently been implemented for regional energy corridor [5–9], river catchment management [10], mapping accessibility patterns of housing development [11], and bicycle facility planning [12], among other applications. However, these applications are either on a town scale (in case of [11]), city scale (in case of [12]) or regional scale (in case of [5–10]) with few numbers of cells (hundreds or thousands) and low resolution (cell area much greater than 2.5 acres).

The GIS component of the GIS-MCDA approaches can be raster- or vector-based models. Vector-based models use *X* and *Y* coordinates to define the locations of points, lines, and areas that correspond to map features. As such, vector data tend to define centers and edges of features. In contrast, raster-based models use a matrix of square areas to define where features are located. These squares, also called cells or pixels or grids, typically are of uniform size, and their size determines the detail that can be maintained in the dataset. Since raster data represent square areas, they describe interiors rather than boundaries, as in the case with vector data. Vector data are excellent for capturing and storing spatial details, while raster data are well suited for capturing, storing and analyzing data that vary continuously from location to location, such as elevation, population, and other datasets considered in this paper, There have been applications that combine both raster and vector data models. The approach described in this paper is a raster-based model. The GIS-based MCDA approach can provide unbiased information to policy-makers. In such cases, the approach does not weigh or rank the model criteria differently. The approach described in this paper assumes the same weight for all criteria; this is needed to provide an unbiased assessment for policy-makers.

Our contributions in this paper are: (1) the ability to perform siting analysis at a high resolution of 100 m by 100 m, which to the best of our knowledge is a much higher resolution than what is currently available for other US-wide siting applications; (2) the development of an approach that is easily applicable to other energy sources once the required siting criteria have been defined, which provides the utility companies and policy makers an easy access to siting and policy related insights for any energy generation option; (3) the development of an approach that is applicable on a national scale, but simultaneously informs local, state, and regional energy policy decisions; (4) the development of a platform for integrating siting decisions with energy economic models based not only on what is required and possible but also what is viable in terms of economic factors such as proximity to load centers and the grid; (5) the development of new siting criteria for various energy technologies, such as CAES, CCS, and CS, through the adaptation of existing regulatory criteria; and (6) the development of a methodology for estimating low-flow statistics for all major streams and waterways in the contiguous United States. To the best of our knowledge, all these contributions are improvements over the state-of-the-art.

The remainder of this paper is organized as follows. Section 2 discusses the proposed spatial multi-criteria design analysis methodology. Section 3 presents an application of the OR-SAGE tool for siting energy storage plants. Section 4 discusses the application of OR-SAGE tool for modeling energy policy. A short summary concludes the paper in Section 5.

2. A GIS-based multicriteria decision analysis approach for siting plants

Current approaches for selecting new plant sites do not provide a global assessment of siting opportunities; furthermore, these approaches are not useful for modeling state, regional, and national energy policy scenarios simultaneously. In this section, a bottom-up GIS-based multicriteria decision analysis approach is described. The GIS-based MCDA approach for siting power generating plants can be described as a process that combines and transforms spatially referenced datasets (inputs) into a resultant base map (output). The overall framework of the proposed approach consists of six steps as shown in Fig. 1. The rest of this section describes each of the steps.

2.1. Selecting the input data

The first step is identifying the required data for screening siting areas. Data sets that are critical to siting power generation plants are identified through published regulations, reports, and articles on siting power generation plants. For example, the nuclear energy industry has well documented regulatory guidelines through the Nuclear Regulatory Commission (NRC), its regulatory body in the US. In addition, the utility industry relies on the Electric Power Research Institute (EPRI) to conduct research and development for utility engineering challenges across all energy sectors. Using references and guidelines from specific regulatory and siting guidelines such as the Nuclear Regulatory Commission (NRC) Regulatory Guide 4.7 [13] and Electric Power Research Institute (EPRI) guidelines [14] provides real world value to the OR-SAGE tool. Criteria were chosen with an attempt to cover all reasonably foreseeable risks and operational requirements for each power generation source, while avoiding unnecessary redundancy of measures. It should be noted that only criteria that can be modeled spatially are considered in this tool. Furthermore, since there are no known regulatory guides for siting advanced coal, concentrated solar plants, or compressed air energy storage plants, the NRC guide 4.7 in conjunction with published reports [15–18] on the engineering and operational principles of these plants were adapted to propose siting screening criteria for evaluating these energy technologies.

Table 1 summarizes the criteria for each of the four energy options discussed in this paper as well as the data source for each criterion. It should be noted that concentrated solar power is of two technologies. One technology uses the solar thermal energy at about 600 °C to drive a steam turbine to generate electricity; this technology uses water from streams and it is called the wet option