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Multicriteria GIS modeling of wind and solar farms in Colorado

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ABSTRACT

The majority of electricity and heat in Colorado comes from coal and natural gas; however, renewable energy sources will play an integral role in the state's energy future. Colorado is the 11th windiest state and has more than 250 sunny days per year. The objectives of this research are to: 1) determine which landcover classes are affiliated with high wind and solar potential; and 2) identify areas that are suitable for wind and solar farms using multicriteria GIS modelling techniques. Renewable potential (NREL wind speed measurements at 50 m above the ground and NREL annual insolation data), landcover, population density, federal lands, and distance to roads, transmission lines, and cities were reclassified according to their suitability. Each was assigned weights based on their relative importance to one another. Superb wind classes are located in high alpine areas. Unfortunately, these areas are not suitable for large-scale wind farm development due to their inaccessibility and location within a sensitive ecosystem. Federal lands have low wind potential. According to the GIS model, ideal areas for wind farm development are located in northeastern Colorado. About 41 850 km^2 of the state has model scores that are in the 90–100% range. Although annual solar radiation varies slightly, inter-mountain areas receive the most insolation. As far as federal lands, Indian reservations have the greatest solar input. The GIS model indicates that ideal areas for solar development are located in northwestern Colorado and east of Denver. Only 191 km^2 of the state had model scores that were in the 90–100% range. These results suggest that the variables used in this analysis have more of an effect at eliminating non-suitable areas for large-scale solar farms; a greater area exists for suitable wind farms. However, given the statewide high insolation values with minimal variance, solar projects may be better suited for small-scale residential or commercial projects.

1. Introduction

Greenhouse gases concentrations have risen over the last 250 years from greater fossil fuel use, modern wide-scale agriculture, and land use alteration [1]. According to ice core data, current carbon dioxide and methane concentrations are greater than at any point in the last 650 000 years [1]. Although fossil fuels are still plentiful and inexpensive, the threat of global warming has caused many to explore a switch to alternative, renewable energy sources.

Approximately 98% of energy produced in Colorado comes from fossil fuels [2]. More specifically, 72% of electricity comes from coal and 75% of homes rely on natural gas for heat [3]. Despite this, it is projected that renewable energy sources, such as wind and solar power, will play an integral role in the future. Colorado is the 11th windiest state [2,3]. Estimates suggest that Colorado, with more than 250 sunny days per year, could generate as much as 83 000 000 MW-hours of electricity from solar technologies on a yearly basis [2,3]. The Governor's Energy Office has shown interest in exploring clean, renewable energy by supporting outreach programs such as the Wind for Schools program for rural teachers and students. An anemometer loan program has recently been created to examine local wind potential. Financial incentives for investing in renewable energy are numerous [2]. With the passing of the American Recovery and Reinvestment Act, Governor Ritter believes that Colorado's New Energy Economy will be enhanced, providing new green jobs across the state [2]. With renewed interest and financial support, geographic areas that are ideal for large-scale wind and solar farms must be located.

Suitability mapping involves using a variety of data sources in which weights are assigned to geographical criteria. Data are often imported into a Geographic Information System (GIS), which combines potentially unrelated data in a meaningful manner. Weights that emphasize the relative importance of one criterion to another are often determined by managers, research specialists, stakeholders, or interest groups to enhance decision-making. A variety of environmental, transportation, planning, waste management, water resources, forestry, agriculture, housing, and natural hazard applications have been undertaken using GIS multicriteria modeling techniques [4–15].

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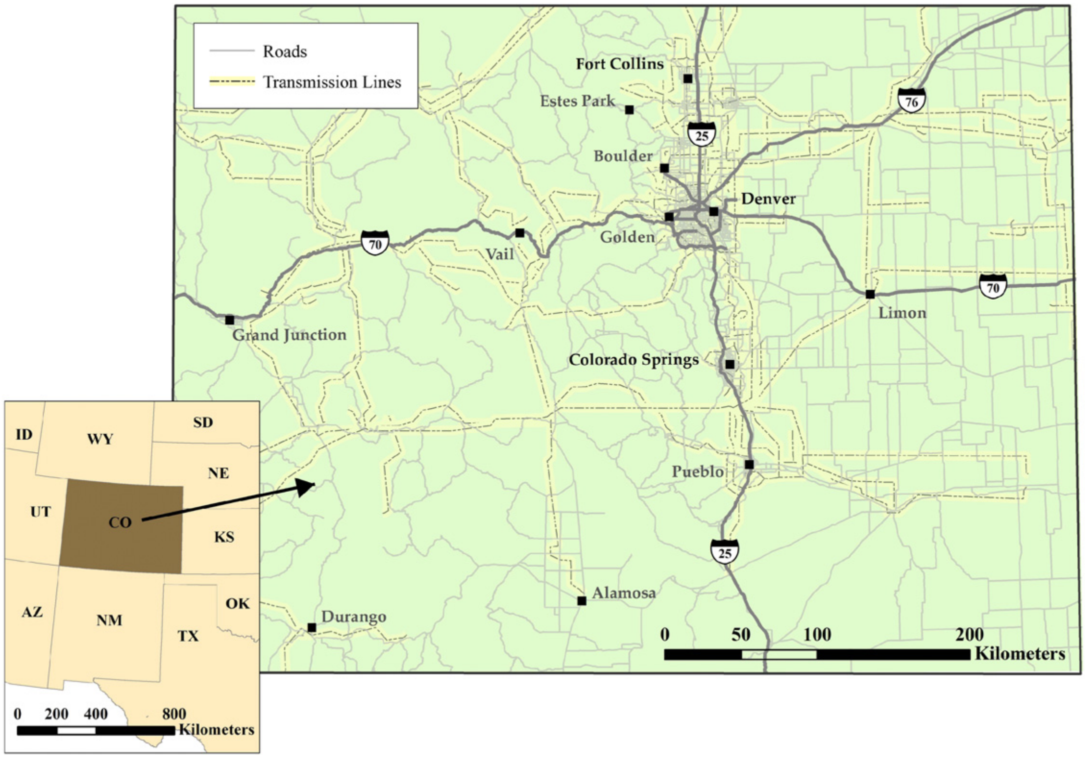

Fig. 1. Location of major roads, cities, and transmission lines in Colorado.

Multicriteria analysis in a vector data model (discrete point, line, and polygon representations) often involves Boolean operators such as AND or OR [16]. An AND operator (intersection) can result in rigid solutions – a variable meets the criterion or it does not. An OR operator (union) is very liberal – results will be included even if a single variable meets the criterion. Multicriteria analysis in a raster data model (continuous grid-based representations) allows more trade-off among variables – a low score on criterion can be offset by a high score on another [16]. GIS data model selection can lead to different optimal solutions [16]. For the aforementioned reasons, most researchers prefer using a combination of data models to control the degree of substitutability among criteria.

Questionnaires reveal that common criteria and meaningful weights are often difficult to define [17]. According to surveys of the public and private sectors, criteria for wind farms include avoiding mountain summits, steep slopes, woodlands, or dense populations. Ideally, sites should also be close to roads and the existing power grid system [17,18]. When modeling solar farms, the number of sun hours, irradiance, temperature, and aspect must be taken into account to maximize potential. Geographic variables such as landcover or vegetation that increases shading, access to highways for maintenance and repair, population density, and location of substations also play a role [19].

The objectives of this project are twofold: 1) explore which landcover classes have high wind or solar potential in Colorado based on existing National Renewable Energy Laboratory (NREL) data sets; and 2) identify areas are suitable for wind or solar farm development using multicriteria GIS modelling techniques.

2. Methods

The following variables were obtained from digital databases: NREL wind speed and solar potential classes, landcover, population density, federal lands, and location of roads, transmission lines, and

Table 1
GIS criteria used to model wind and solar farms.

Variable	Ideal Conditions	Original Data	Type	Final Data	Type	Possible Values	Weight	Original Resolution	Final Resolution
Wind Potential	NREL Class 7 (superb)	Categorical	Grid	Categorical	Grid	[0.14, 0.29, 0.43, 0.57, 0.71, 0.86, 1.00]	3	200 m	1500 m
Solar Potential	Maximize W/m^2/day	Continuous	Grid	Continuous	Grid	[0–1]	3	40 000 m	1500 m
Distance to Transmission Lines	Closer to Transmission Lines	Discrete	Line	Continuous	Grid	[0–1]	2	NA	1500 m
Distance to Cities	Far Away from Cities	Discrete	Point	Continuous	Grid	[0–1]	1	NA	1500 m
Population Density	Low Population Density per Block Group	Categorical	Polygon	Categorical	Grid	Discrete Values Ranging from [0–1]	1	NA	1500 m
Distance to Roads	Close to Roads	Discrete	Line	Continuous	Grid	[0–1]	1	NA	1500 m
Landcover	Short Vegetation, Subdued, Stable Topography	Categorical	Polygon	Categorical	Grid	[0.33, 0.67, 1.00]	1	NA	1500 m
Federal Lands	Not in Federal Lands	Categorical	Polygon	Categorical	Grid	[0, 1]	1	NA	1500 m