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Mitigating the Effects of Climate Change with Wind Energy and GIS

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Authors' contributions

This work was carried out in collaboration between all authors. Author RI designed the study, wrote the first draft of the manuscript and managed the initial literature searches. Authors RS and MS revised the final manuscript and contributed to the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The climate is changing, and humans are heavily exacerbating these changes. As the effects of climate change are being felt across the planet, scientists and policy makers are uniting to increase mitigation efforts and are researching renewable, clean energy sources to reduce the amount of greenhouse gas emissions released into the atmosphere during energy production. Of the different renewable energy technologies, wind energy is one of the most researched and implemented. Over the past twenty years, researchers have been applying Geographic Information Systems (GIS) to their climate change studies. GIS allows the user to spatially view, manipulate, and analyze data to determine patterns, trends, and relationships. This paper examines the use of GIS as a tool in wind power studies to locate potential wind farm sites, model wind farm energy output, and assess the potential for implementing wind energy.

Keywords: Climate change; wind energy; geographic information systems; GIS; greenhouse gases.

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1. INTRODUCTION

While weather refers to specific spatial and temporal atmospheric conditions, climate refers to the statistics of weather over an extended period of time. Generally, a location's climate is determined by statistically analyzing the weather conditions over a period of at least 30 years, which is the minimum time necessary to determine the normal or average climate of an area according to the World Meteorological Organization (WMO) [1]. Climate change refers to the long-term changes that occur in these weather statistics and the anomalies from the statistical averages [2]. There is much evidence to prove that climate change is a natural process and has been occurring for hundreds of thousands of years. Through paleoclimatology and by studying Antarctic ice cores, scientists have discovered that the Earth's climate has naturally varied over the past 420,000 years. The variations noted include changes in regional temperature patterns, precipitation amounts and patterns, and the prevalence of the atmospheric gases in the atmosphere. However, scientists have also discovered that human influences are drastically altering the natural composition of the atmosphere resulting in expedited climate changes beyond what should be naturally occurring.

Earth is characterized by a natural greenhouse effect that keeps the surface relatively warm. This greenhouse effect occurs as the greenhouse gases reflect the emitted long wave radiation back to the surface, creating a blanket covering Earth's surface [3]. Several different gases contribute to the greenhouse effect; on average, approximately 60% is water vapor, 25% is carbon dioxide, 8% is ozone, and the remaining 7% is composed of trace gases which include methane and nitrous oxide [4]. These gases are naturally present in Earth's atmosphere, but over the years, human activities have increased their concentrations and therefore altered the natural composition of the atmosphere. As the greenhouse gas concentrations increase, more long wave radiation is reflected back to Earth's surface and a general warming trend is observed. According to the Environmental Protection Agency (EPA, 2014) during the past 100 years, the average temperature of Earth's surface has risen by 1.5° Fahrenheit (F) and is expected to rise an additional 2-11.5° F over the next century. In order to mitigate human influences on climate change, scientists, policy makers, and world leaders are looking at ways to reduce the amount of human induced greenhouse gases emitted into the atmosphere.

Due to the rising costs and limited quantities of fossil fuels, the large amounts of greenhouse gases being emitted globally and the growing concern for the effects of climate change, the United States and other countries have realized the necessity of developing and implementing sustainable energy into their power supply systems. Like most developed countries, the United States' electricity sector is primarily dependent on electricity generated from fossil fuels [5]. In the United States as of 2013, thirty-three percent of greenhouse gas emissions are produced through electricity production, which is higher than any other economic sector, even transportation [6]. This has given rise to an increase in research, development, and implementation of clean energy systems around the world. The United States Department of Energy predicts that there will be a fifty-two percent increase in total renewable generating capacity from 2012 to 2040 [7]. Additionally, numerous recent studies have concluded that the advantages of renewable energy are vast, making alternative energy sources extremely attractive, especially when coupled with their natural abundance [8].

2. WIND POWER

One of the most popular renewable energy technologies being developed and applied today is wind energy [9]. For as long as can be remembered, humans have been exploiting wind power to ease their daily struggles. Early civilizations initially harnessed wind power in marine applications for trade, travel, and to obtain resources, but as civilizations advanced, wind power was increasingly employed. By the 1800's, it is estimated that approximately twenty-five percent of Europe's industrial power was supplied by wind energy, and in 1888, wind power was first used to generate electricity in the United States by scientist and inventor Charles Brush [10]. While innovation and development of wind turbines continued in the U.S. throughout the 20th century, it occurred sporadically and mostly in rural areas. The next big milestone in the advancement of wind energy in the U.S. came in 1982 with the development of the first wind farm in California [11]. By the mid-1980s there were thousands of wind systems operating in California but these were met with predominantly negative views by the public.

Because of this negative public opinion and the fact that wind turbines still struggled in efficiency, the implementation of wind energy into the U.S. energy market basically ceased in the late 1990s. However, as technology improved, public opinion changed, and as incentives for using clean energy became available, the development and implementation of wind farms began to increase drastically. The last decade alone has seen enormous advancements in technology and utilization of wind energy. From 2000-2012, the U.S. increased its annual wind electricity generation from 5,593 gigawatt hours (GWh) to 140,089 GWh, and these numbers continue to climb [12].

Wind energy and wind farms are appealing for several reasons. Wind farms can be constructed locally, which provides a domestic power supply. This is becoming increasingly important as fossil fuels become more limited and foreign tensions grow with countries that have access to the majority of the supply of these limited resources. That being said, utilizing wind power improves national security and the economy by allowing the U.S. to be energy independent and allowing more diversity in the energy sector. It also improves overall public and environmental health by reducing greenhouse gas emissions and pollution from fossil fuels.

Despite the benefits of wind energy, it has drawbacks and challenges as well. When considering implementing wind energy, there are social, economic, and environmental implications that must be considered in addition to the natural meteorological variability associated with harvesting wind energy. Wind farm sites are determined based on the wind potential of an area and environmental agreeability. However, wind turbines raise concern for the disruption of ecosystems and conflictions with nature conservation [13]. Aydin et al. [14] conclude that "the environmental impacts of wind energy which are commonly accepted by scientists are generally listed as effects on animal habitats such as bird collisions, noise generation, visual impact, safety issues, and electromagnetic interference." However, most concede that the environmental benefits of wind turbines in regards to climate change mitigation outweigh the drawbacks.

3. GEOGRAPHIC INFORMATION SYSTEMS

Scientists and engineers are constantly looking to improve our current understanding of wind energy and develop more efficient methods of harnessing and utilizing it. One such toolbox used to enhance their overall understanding of wind energy and improve the implementation metrics is through the use of Geographic Information Systems (GIS). GIS incorporates both hardware and software to view, analyze, manipulate and develop spatial relationships in geographically referenced data. GIS is a very versatile tool and can be applied to virtually any subject area. What makes it so adaptable and appealing is its ability to quickly provide the user with qualitative and quantitative answers to questions, its magnitude of performance and analysis capabilities, and its ease at revealing relationships and trends in data [15].

Through the utilization of GIS, users are able to broaden the extent of their research, partake in multidisciplinary research projects, and enhance communication of scientific findings. However, GIS has its limitations as well. As with all other analysis tools, an analysis performed using a GIS is only as trustworthy and accurate as the input data. Because of the immense amount of free GIS data available, users must remain aware of the credibility of the sources and databases. Additionally, GIS are limited in their ability to show spatiotemporal changes or relationships and are best suited to static spatial datasets where analyses are mostly two dimensional. This temporal limit is the major reason that GIS is not used as widely as other applications and software systems in meteorology and similar Earth sciences; meteorological studies are heavily reliant on the ability to view and analyze real-time data [16]. However, GIS is still heavily utilized in fields with meteorological applications, such as the renewable energy sector.

Numerous papers and other works have been published in which GIS is applied to clean energy research within the realm of wind energy. For example, Griffiths and Dushenko [17] demonstrated that GIS suitability mapping is useful in quantifying the ecological impacts of wind farms. Berry et al. [18] developed an online GIS to enable the public to visualize the impacts a wind farm might have on the local community. Grassi et al. [19] used a GIS to estimate the wind energy potential of the state of Iowa. Riddington et al. [20] employed a GIS model in conjunction with an internet survey to assess the effect of wind farms on tourism in Scotland and found a slight negative impact. Even countries like Iran, which has substantial oil reserves [21], and

China with its ample coal resources are conducting GIS suitability analyses of wind farm locations to meet the needs of rural populations [22].

4. CASE STUDIES

Three case studies that focus on GIS applications for locating potential sites for wind farms are identified and evaluated in this paper. These case studies explore the possibility of implementing wind power at the community, state, and national level. Each study is evaluated based on the effectiveness of the methodologies used to obtain the project goals and the efficacy of the project in comparison to one another and other studies that have been performed.

Case Study 1 was conducted by Hoesen and Letendre [23] and evaluated the potential for implementing renewable energy into the small, rural community of Poultney, Vermont, in an effort to localize their energy dependence. This project aimed to produce visualizations depicting potential locations of wind farms that could be used by community leaders in participatory community energy planning. The researchers began the analyses for wind energy potential by obtaining a 30-m digital elevation model (DEM) from the National Elevation Dataset (NED) and the 50-m wind class dataset for Vermont from the National Renewable Energy Laboratory (NREL), and then reclassifying the wind data according to assumptions they deemed appropriate. These assumptions as well as their data sources and reclassification decisions are summarized in Table 1. Slopes greater than 60 degrees were excluded as were locations outside an elevation range of 600-1050 meters. The study accounted for vegetation shielding by applying a tree canopy height dataset obtained from the 2000 National Biomass Carbon Dataset. Hoesen and Letendre explained the necessity of this in order to analyze the aesthetic impact the wind turbines could have on the public. The visual impact was determined using Viewshed software, which determines the raster surface locations visible to a set of observer features assuming that a Clipper Windpower 2.5 MW C96 turbine at a height of 80 meters was installed taking into account topographic characteristics. The study found six locations that could potentially be used as sites for wind turbines in the northeast region of Poultney. The locations are extremely promising for wind energy potential, but also suggest neighboring towns will experience large visual impacts. This case study is extremely useful in showing how GIS can be applied to map small scale wind energy potential.

In Case Study 2, Janke [24] evaluated the potential for wind energy in the state of Colorado. For his analysis, Janke's objectives were to explore which landcover classes have high wind potential based on existing National Renewable Energy Laboratory (NREL) data sets and to identify areas that are suitable for wind farm development using multi-criteria GIS modeling techniques. To begin the analysis, Janke first obtained the following variables from online datasets: wind speed, landcover, population density, federally owned lands, transportation network, transmission lines, and cities. The NREL wind speed data are based on observed wind speeds 50 meters above ground level (AGL) for 2003-2004 and were produced at a spatial resolution of 200 meters. The wind data were categorized on a scale from 0-1 and rescaled to a spatial resolution of 1500 meters by averaging pixel values. The transmission grid data were also obtained from NREL and rescaled from 0-1 with 0 being farthest away and 1 being closest at a 1500 meter spatial resolution. Point data of cities were obtained along with the 2000 population density and a dataset of the Colorado road networks. All three were reformatted to mirror the 1500 meter spatial resolution and the 0-1 efficiency scale. Locations farther away from cities with lower population density and close to existing roads were thought to be more appropriate and assigned a value of 1. The land cover dataset was broken into three categories based on the potential for development, and the federal land data were used to eliminate land where renewable energy sites could not be constructed such as National Parks and Native American Reservations. Each dataset was weighted based on importance. Wind data were weighted the highest value of three, the transmission grid data were weighted two, and all other datasets were weighted equally as one. This study's GIS criteria are summarized in Table 2.

Janke concluded from his GIS analysis that the greatest potential for larger wind farms exists north of Fort Collins, Colorado, in the northeastern portion of the state. Additionally, the analysis found that there is a location just west of Boulder, Colorado, that could provide electricity to a more populated urban region. Janke also found that existing Colorado wind farms coincided well with the results from his project suggesting that his modeling techniques were valid. For example, an existing 11,000 acre wind farm and cattle ranch in Prowers County, Colorado, received a suitability score of 70% based on the parameters of Janke's study.

Like those in the United States, some leaders in the United Kingdom recognize the need to mitigate environmental degradation from greenhouse gas emissions and acid rain by implementing renewable energy into the energy grid. In Case Study 3, Baban and Parry [25] aimed to understand the factors involved in selecting suitable sites for wind farms through the use of GIS. Their analysis is unique as it began with a questionnaire that was sent via postal mail to public and private sectors inquiring on the criteria and government policies deemed appropriate by both to identify potential wind farm locations. The researchers found that certain criteria were favored regarding wind speed, distance from urban development, and land characteristics. Optimal wind speed ranged from 7-15 meters per second, minimum distance from urban development ranged from 500-5000 meters, and the ideal terrain was described as flat or slightly hilly with a slope of no more than 10 percent. The questionnaire also found that there were no significant government policies applicable as most organizations stated, "whatever policies are at present operational," would suffice. After organizing the questionnaire results and an additional literature review, Baban and Parry concluded that the development criteria included "topography, wind speed and direction, land use/cover, population, access, hydrology, ecology, and resources."

The next step was to specify the criteria that would be used in the GIS model. A suitable location would have wind speeds primarily above 5 meters per second, be located a minimum of 500 meters away from forests but within 2000 meters of urban development, be within 10,000 meters of roads, and not be within 1000 meters of ecological or scientifically appealing land or historic sites. They obtained the necessary data and imported each dataset into a GIS for easier manipulation and analysis. The data were reclassified based on attributes, a buffer, and weighted based on importance. After each dataset was reclassified and weighted, Baban and Parry combined all of the 14 different data layers. This resulted in a map of the study area showing the best locations for potential wind farm sites. Baban and Parry found the potential wind farm locations were strongly influenced by the road buffer and urban development buffer. They concluded that other datasets could easily be added or exchanged based on the decision maker's preferences, and "additional relevant layers of information, such as public satisfaction, could be formatted and easily integrated into the GIS, and, consequently, be taken into consideration when locating wind farms."

Table 1. Summary of the data, assumptions, and reclassification decisions for Case Study 1

Data	Assumptions	Wind power classifications
- 30-m DEM from NED - 50-m NREL wind class dataset - 30-m canopy height from the 2000 National Carbon Biomass Dataset - Building locations and town boundaries - Slope data was derived	- Slopes less than 60° - Elevation between 600 and 1050 m - Variations in canopy are accurately represented in the vegetation height layer	- None: 0 - Poor: 1 - Marginal: 2 - Fair: 3 - Good: 4 - Excellent: 5 - Outstanding: 6

Table 2. GIS criteria used by case study 2 to determine potential wind farms

Variable	Ideal conditions	Weight
- Wind potential	- NREL class 7	3
- Distance to transmission lines	- Locations closer to transmission lines	2
- Distance to cities	- Farther from cities	1
- Population density	- Low population density per group	1
- Distance to roads	- Closer to roads	1
- Landcover	- Constant topography; short vegetation	1
- Federal lands	- Exclude federal lands	1

5. DISCUSSION

Each of the previous case studies took a unique approach to evaluating the potential for wind farms in their given study areas. However, it is safe to say that the case studies differ in their scope and the depth of their analyses. Additionally, the true complexity of accurately determining feasible locations for wind farms exceeds what is covered in any of the case studies.

When evaluating the potential for wind power in a given region, a basic methodology can be followed in which four fundamental concepts are analyzed: the theoretical potential, available potential, technological potential, and the economic potential [26]. The theoretical potential simply estimates the existing wind characteristics (i.e. the maximum wind energy generated in a location). The available potential is the portion of the theoretical potential that can be obtained without any negative environmental impacts after considering factors such as topographic characteristics, proximity to towns, and excluded land. The technological potential is determined by the assessing the existing technological capabilities and the economic potential can be established by contemplating the economic feasibility of generating wind power. To achieve this, the economic potential considers proximity to existing roads and transmission grids as well as predicted profitability. All three case studies evaluated the theoretical potential, the available potential, and the economic potential of wind power, but only Hoesen and Letendre admit an awareness of the technological potential and limitations of their study. For example, the researchers reveal the model and height of the wind turbine used in their evaluation. However, the technological potential could be further tested by evaluating the wake effect on the theoretical wind turbines in the region. Grassi [27] provides an innovative methodology to evaluate the impacts of wake effect on energy output. Wake effect is a stream of turbulent wind that flows behind the wind turbines at a decreased speed [28]. If this concept of quantifying the impacts of wake effect were to be combined with a methodology of appropriately spatially distributing wind farms to reduce the variability of energy output, one could better validate the output results for potential wind farms [29]. This would also allow researchers to determine whether a certain dimension of available land is necessary for accurate results.

In addition to these four basic concepts, public opinion must be considered when determining locations for potential wind farms. Past research documents the “strong argumentative views” associated with wind energy between public and private organizations according to Kyriakopoulos [30]. Additionally, several studies discuss the significance of engaging the public in environmental planning and different methods of achieving this objective [31,32]. Such studies assess the efficiency of a web-based GIS tool or participatory GIS applications that are interactive, increase public involvement, and thereby decrease disputes over environmental management decisions [33,34] including the decisions made on locations of wind farms [35,36]. Of the case studies evaluated in this review, Hoesen and Letendre (case study 1) developed their output maps specifically for community energy planning while Janke (case study 2) and Baban and Perry (case study 3) acknowledge that their methodologies may have to be altered or adapted to include public opinions.

The effectiveness of the multi-criteria, GIS-based analysis performed in each case study needs be evaluated. A multi-criteria, GIS-based analysis identifies a relationship between the input data and the output map [37]. In general, there is much debate as to the best practice for these types of analyses, especially in regards to land-use suitability evaluations [38]. Some literature indicates a general inadequacy in using Boolean logic and encourages the use of an innovative technique using fuzzy logic in which a weighted average is determined by comparing a set of values on a given scale. These values are then translated to a relatable scale in which they are normalized [39]. Janke acknowledged the complexity involved with a multi-criteria analysis and concluded that it is best to use multiple data models to better control the extent to which the criteria is alternated. Baban and Parry also performed a combination of Boolean and fuzzy logic in determining the weights of the criteria. Hoesen and Letendre manually scaled their criteria to create binary or Boolean outputs as well as ordinal-scale outputs.

One final point that should be considered when attempting to accurately determine feasible locations for wind farms is the possibility of evaluating the theoretical farm against changes in atmospheric conditions. This approach could be useful for verifying the results of wind farm suitability analyses as project result validation is largely lacking in the case studies and other literature [40]. Previous research documents how wind farm productivity can be tested against local and mesoscale atmospheric characteristics and atmospheric stability [41].

6. CONCLUSION

In an effort to minimize the emissions of greenhouse gases generated in energy production, many countries are turning to environmentally friendly, renewable energy sources. Of the many different types of renewable energy, wind energy has a long history of providing power to humans even before electricity was conceptualized. Wind energy has been the most widely researched and implemented instrument in the past decade as technological advancements in the wind turbine and research methods have grown. One such advancement is the use of GIS to depict spatial relationships among an infinite amount of datasets. Based on the three case studies evaluated, it has been shown that GIS has been heavily utilized to identify locations of possible wind farms at the local, state, and national level. All case studies concluded that wind speed, land characteristics, and proximity to urban development and existing road networks are among the most important factors when considering the location of a wind farm site. The methodologies used in these case studies could easily be applied to other areas in order to map potential locations for wind farms. Additional criteria and potential verification techniques should also be considered to improve GIS-based wind farm location analyses. In short, wind energy offers a clean, cost-effective, inexhaustible, and readily available means of helping to mitigate climate change while answering the increasing demand for electricity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Arguez A, Vose R. The definition of the standard WMO climate normal: The key to deriving alternative climate normal. Bulletin of the American Meteorological Society. 2011;92:699-704.
2. National Weather Service. Climate change. Accessed 12 September 2014. Available:www.nws.noaa.gov/om/brochures/climate/Climatechange.pdf
3. Le Treut H, Somerville R, Cubasch U, Ding Y, Mauritzen C, Mokssit A, et al. Historical overview of climate change. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Miller HL, editors. Climate change 2007: The physical science basis. New York: Cambridge University Press; 2007.
4. Karl TR, Trenberth KE. Modern global climate change. Science. 2003;302(12):1719-1722.
5. Carley S, Andrews RN. Creating a sustainable U.S. Electricity sector: The question of scale. Policy Sciences. 2012;45:97-121.
6. Environmental Protection Agency. Sources of greenhouse gas emissions. Accessed 9 September 2014. Available:www.epa.gov/climatechange/ghgemissions/sources.html
7. DOE. Annual energy outlook 2014. Washington, DC; 2014.
8. Marquis M, Wilczak J, Ahlstrom M, Sharp J, Stern A, Smith J, et al. Forecasting the wind to reach significant penetration levels of wind energy. Bulletin of the American Meteorological Society. 2011;92:1159-1171.
9. Ramachandra TV, Shruthi BV. Wind energy potential mapping in Karnataka, India, using GIS. Energy Conversion and Management. 2005;46:1561-1578.
10. Gipe P. Wind energy, history of. In: Encyclopedia of energy. Cleveland CJ, editor. Philadelphia: Elsevier; 2004.
11. Vaughn JN. Wind energy: Renewable energy and the environment. London: CRC Press; 2013.
12. Gelman R, Meshek M, Buchanan S, Augustine E. 2012 renewable energy data book. Accessed 9 September 2014; 2013. Available:www.nrel.gov/docs/fy14osti/60197.pdf
13. Krewitt W, Nitsch J. The potential for electricity generation from on-shore wind energy under the constraints of nature conservation: A case study for two regions in Germany. Renewable Energy. 2003;28(8):1645-1655.
14. Aydin NY, Kentel E, Duzgun S. GIS-based environmental assessment of wind energy systems for spatial planning: A case study from western Turkey. Renewable & Sustainable Energy Reviews. 2010;14(1):364-373.

15. ESRI. What is GIS? 2011.
Accessed 3 September 2014.
Available:www.esri.com/what-is-gis/overview#overview_panel
16. Wilhelmi OV, Brunskill JC. Geographic information systems in weather, climate, and impacts. Bulletin of the American Meteorological Society. 2013;84(10):1409-1414.
17. Griffiths JC, Dushenko WT. Effectiveness of GIS suitability mapping in predicting ecological impacts of proposed wind farm development on Aristazabal Island, BC. Environment, Development, and Sustainability. 2011;13(6):957-991.
18. Berry R, Higgs G, Fry R, Langford M. Web-based GIS approaches to enhance public participation in wind farm planning. Transactions in GIS. 2011;15(2):147-172.
19. Grassi S, Chokani N, Abhari R. Large scale technical and economical assessment of wind energy potential with a GIS tool: Case study Iowa. Energy Policy. 2012;45:73.
20. Riddington G, McArthur D, Harrison T, Gibson H. Assessing the economic impact of wind farms on tourism in Scotland: GIS, surveys and policy outcomes. International Journal of Tourism Research. 2010;12(3):237.
21. Azizi A, Malekmohammadi B, Jafari H, Nasiri H, Amini Parsa V. Land suitability assessment for wind power plant site selection using ANP-DEMATEL in a GIS environment: Case study of Ardabil province, Iran. Environmental Monitoring and Assessment. 2014;186(10):6695-6709.
22. Byrne J, Zhou A, Shen B, Hughes K. Evaluating the potential of small-scale renewable energy options to meet rural livelihoods needs: A GIS- and lifecycle cost-based assessment of Western China's options. Energy Policy. 2007;35(8):4391.
23. Hoesen JV, Letendre S. Evaluating potential renewable energy resources in Poultney, Vermont: A GIS-based approach to supporting rural community energy planning. Renewable Energy. 2010;35:2114-2122.
24. Janke JR. Multicriteria GIS modeling of wind and solar farms in Colorado. Renewable Energy. 2010;35:2228-2234.
25. Baban SM, Parry T. Developing and applying a GIS assisted approach to locating wind farms in the UK. Renewable Energy. 2001;24:59-71.
26. Voivontas D, Assimacopoulos D, Mourelatos A. Evaluation of renewable energy potential using a GIS decision support system. Renewable Energy. 1998;13(3):333-344.
27. Grassi S, Junghans S, Raubal M. Assessment of the wake effect on the energy production of onshore wind farms using GIS. Applied Energy; 2014.
28. Diamond K, Crivella E. Wind turbine wakes, wake effect impacts, and wind leases: Using solar access laws as the model for capitalizing on wind rights during the evolution of wind policy standards. Duke Environmental Law & Policy Forum. 2011;195-244.
29. Cassola F, Burlando M, Antonelli M, Ratto C. Optimization of the regional spatial distribution of wind power plants to minimize the variability of wind energy input into power supply systems. Journal of Applied Meteorology and Climatology. 2008;47:3099-3116.
30. Kyria kopoulos G. Power as resource-power as discourse: An overview evaluation of the key-factors of “wind farms” and “riparian rights” as sources of power. Engineering. 2011;3:63-72.
31. Higgs G, Berry R, Kidner D, Langford M. Using IT approaches to promote public participation in renewable energy planning: Prospects and challenges. Land Use Policy. 2008;25:596-607.
32. Ek K, Persson L. Wind farms-where and how to place them? A choice experiment approach to measure consumer preferences for characteristics of wind farm establishments in Sweden. Ecological Economics. 2014;105:193-203.
33. Kyem PA. Of intractable conflicts and participatory GIS applications: The search for consensus amidst competing claims and institutional demands. Annals of the Association of American Geographers. 2004;94(1):37-57.
34. Boroushaki S, Malczewski J. Participatory GIS: A web-based collaborative GIS and multicriteria decision analysis. URISA Journal. 2010;22(1):23-32.
35. Berry R, Higgs G, Fry R, Langford M. Web-based GIS approaches to enhance public participation in wind farm planning. Transactions in GIS, 2011;15(2):147-172.
36. Sima A, Densham P, Haklay M. Web-based GIS for collaborative planning and

public participation: An application to the strategic planning of wind farm sites. Journal of Environmental Management. 2009;90:2027-2040.
37. Malczewski J. GIS-based land-use suitability analysis: a critical overview. Progress in Planning. 2004;62:3-65.
38. Lee A, Chen H, Kang H. Multi-criteria decision making on strategic selection of wind farms. Renewable Energy. 2009;34:120-126.
39. Malczewski J. Ordered weighted averaging with fuzzy quantifiers: GIS-based multicriteria evaluation for land-use suitability analysis. International Journal of Applied Earth Observation and Geoinformation. 2006;8:270-277.
40. Sliz-Szkliniarz B, Vogta J. GIS-based approach for the evaluation of wind energy potential: A case study for the Kujawsko–Pomorskie Voivodeship. Renewable and Sustainable Energy Reviews. 2011;15:1696-1707.
41. Wharton S, Lundquist J. Atmospheric stability affects wind turbine power collection. Environmental Research Letters. 2012;7:1-9.

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