

Mitigating the Effects of Climate Change with Wind Energy and GIS

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 energy 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

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. Climate change refers to the long-term changes that occur in these weather statistics and the anomalies from the statistical averages [1]. There is much evidence to prove that climate change is a natural process and has been occurring for hundreds of thousands of years. 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 longwave radiation back to the surface, creating a blanket covering Earth's surface [2]. 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 [3]. 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 longwave 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.

39 In order to mitigate human influences on climate change, scientists, policy makers, and
40 world leaders are looking at ways to reduce the amount of human induced greenhouse
41 gases emitted into the atmosphere.

42 Due to the rising costs and limited quantities of fossil fuels, the large amounts of greenhouse
43 gases being emitted globally and the growing concern for the effects of climate change, the
44 United States and other countries have realized the necessity of developing and
45 implementing sustainable energy into their power supply systems. Like most developed
46 countries, the United States' electricity sector is primarily dependent on electricity generated
47 from fossil fuels [4]. Thirty-three percent of greenhouse gas emissions are produced through
48 electricity production, which is higher than any other economic sector, even transportation
49 [5]. This has given rise to an increase in research, development, and implementation of
50 clean energy systems around the world. Additionally, recent studies have concluded that the
51 advantages of renewable energy are vast, making alternative energy sources extremely
52 attractive, especially when coupled with their natural abundance [6].

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54 2. WIND ENERGY

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56 One of the most popular clean energy forms being developed and applied today is wind
57 energy. For as long as can be remembered, humans have been exploiting wind power to
58 ease their daily struggles. In his entry in the *Encyclopedia of Energy*, Gipe [7] explains the
59 question behind the true origin of human utilization of wind energy: "Like the mystery of who
60 invented the wheel, we do not know when humans first employed the force of the wind to do
61 work." In early civilizations, we know that wind power was heavily utilized in marine
62 applications for trade, travel, and to obtain resources. It is known that the Egyptians used
63 sails made of linen and papyrus to navigate the Nile River. However, the first known uses of
64 terrestrial wind power date back to the 10th century in Persia (what is today Iran) when the
65 first windmills were constructed to grind grain and obtain water from streams for irrigation.
66 The ancestor of the modern day windmill, the English post mill, was developed independent
67 of the Persian windmill in 12th century. The post mill differed from the Persian mill in that it
68 rotated about a horizontal axis whereas the Persian mill rotated about a vertical axis.
69 Throughout the next two centuries, the idea of the post mill spread throughout Europe;
70 however, it was widely replaced by a more powerful and innovative design, the tower mill.
71 Between 1300 and the introduction of the steam engine in the 1800s, the tower mill was
72 utilized by various industries including paper companies, lumber companies, and agricultural
73 and is estimated to have supplied Europe with approximately 25% of its industrial energy.

74 Around 1850, the farm windmill began to appear in the Great Plains. The American farm
75 windmill worked to extract groundwater for irrigation purposes which allowed the Great
76 Plains to be so widely utilized for agriculture. By the 1900s, almost all of the American farm
77 windmills were constructed of metal, and it is estimated that between the 1930s and 1940s,
78 over six million of these windmills were operable throughout the Great Plains [8]. However,
79 nearly all of the windmills at this time were solely used for agricultural purposes. The first
80 time that wind energy was used to generate electricity in the U.S. was in 1888 by Charles
81 Brush. Brush, a scientist and inventor from Cleveland, Ohio, developed a 60 foot tall wind
82 turbine in his backyard that stored energy in an array of 12 batteries. Brush used this wind
83 turbine for 20 years to generate his electricity, but it could not generate an efficient amount
84 of electricity when compared to that provided by the city. While innovation and development
85 of wind turbines continued in the U.S. throughout the 20th century, it occurred sporadically
86 and mostly in rural areas. The next big milestone in the advancement of wind energy in the
87 U.S. came in 1982 with the development of the first wind farm in California [8]. By the mid-
88 1980s there were thousands of wind systems operating in California but were met with
89 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 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 [9].

Wind energy and wind farms are appealing for several reasons. Wind farms can be constructed locally, which provide 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 energy 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 its 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 conflicts with nature conservation [10]. Aydin et al. [11] 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 [12].

Additionally, through 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 used. Because of the immense amount of free GIS data available, users must remain aware of the credibility of the sources and databases used to obtain data. 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 [13]. 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.

4. CASES 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 energy at the community, state, and national level. The first study was conducted by Hoesen and Letendre [14] and evaluated the potential for implementing renewable energy into the small, rural community of Poultney, Vermont, in an effort to localize their energy dependence. The researchers began the analyses for wind energy potential by obtaining the wind class dataset for Vermont from the National Renewable Energy Laboratory (NREL) and reclassifying it according to assumptions they saw appropriate. 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 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 a second case study, Janke [15] 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, as were the 2000 population density and a dataset of the Colorado road network. 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 was weighted the highest value of three, the transmission grid data was weighted two, and all other datasets were weighted equally as one.

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

189 Prowers County, Colorado, received a suitability score of 70% based on the parameters of
190 Janke's study.

191 Like those in the U.S., some leaders in the United Kingdom recognize the need to mitigate
192 environmental degradation from greenhouse gas emissions and acid rain by implementing
193 renewable energy into the energy grid. Baban and Parry [16] aimed to understand the
194 factors involved in selecting suitable sites for wind farms through the use of GIS. Their
195 analysis is unique as it began with a questionnaire that was sent via postal mail to public and
196 private sectors inquiring on the criteria and government policies deemed appropriate by both
197 to identify potential wind farm locations. The researchers found that certain criteria were
198 favored regarding wind speed, distance from urban development, and land characteristics.
199 Optimal wind ranged from 7-15 meters per second, minimum distance from urban
200 development ranged from 500-5000 meters, and the ideal terrain was described as flat or
201 slightly hilly with a slope of no more than 10 percent. The questionnaire also found that there
202 were no significant government policies applicable as most organizations stated, "whatever
203 policies are at present operational," would suffice. After organizing the questionnaire results
204 and an additional literature review, Baban and Parry concluded that the development criteria
205 included "topography, wind speed and direction, land use/cover, population, access,
206 hydrology, ecology, and resources."

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

221 222 **CONCLUSION**

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224 In an effort to minimize the emissions of greenhouse gases generated in energy production,
225 many countries are turning to environmentally friendly, renewable energy sources. Of the
226 many different types of renewable energy, wind energy has a long history of providing power
227 to humans even before electricity was conceptualized. Wind energy has been the most
228 widely researched and implemented instrument in the past decade as well as technological
229 advancements in the wind turbine and research methods have grown. One such
230 advancement is the use of GIS to depict spatial relationships among an infinite amount of
231 datasets. Based on the three case studies evaluated, it has been shown that GIS has been
232 heavily utilized to identify locations of possible wind farms at the local, state, and national
233 level. All case studies concluded that wind speed, land characteristics, and proximity to
234 urban development and existing road networks are among the most important factors when
235 considering a location as a wind farm site. The methodologies used in these case studies
236 could easily be applied to other areas in order to map potential locations for wind farms.

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