A Feasibility Analysis of South Carolina Wind Resources for Electric Power Generation

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Renewable Portfolio Standards (RPS) are policy tools that establish a requirement for retailers of electricity to provide a minimum portion of their electricity from renewable resources such as solar, wind, biomass, geothermal, and water. RPSs have been considered by the U.S. Congress; however, all current RPSs have been developed by individual states. In the Southeast, North Carolina has recently completed a study of the feasibility of developing a RPS (La Capra, 2006; GDS Associates, 2006) and RPS legislation has been passed by the state legislature. States that have adopted a RPS cite several benefits (La Capra, 2006):

- In-state economic development;
- Promoting development of cost-effective, environmentally sustainable resources;
- Reducing environmental impacts of electricity generation (pollutants and greenhouse gases);
- Diversifying the available energy resource profile;
- Buffering energy price volatility; and,
- Meeting incremental demand with small-sized renewables rather than dependence on single large facilities.

South Carolina likely has similar renewable energy resources to North Carolina. This commonality, coupled with a similar socioeconomic make-up, and given the success of the North Carolina RPS, suggests that analysis of developing a RPS in South Carolina is a significantly beneficial endeavor.

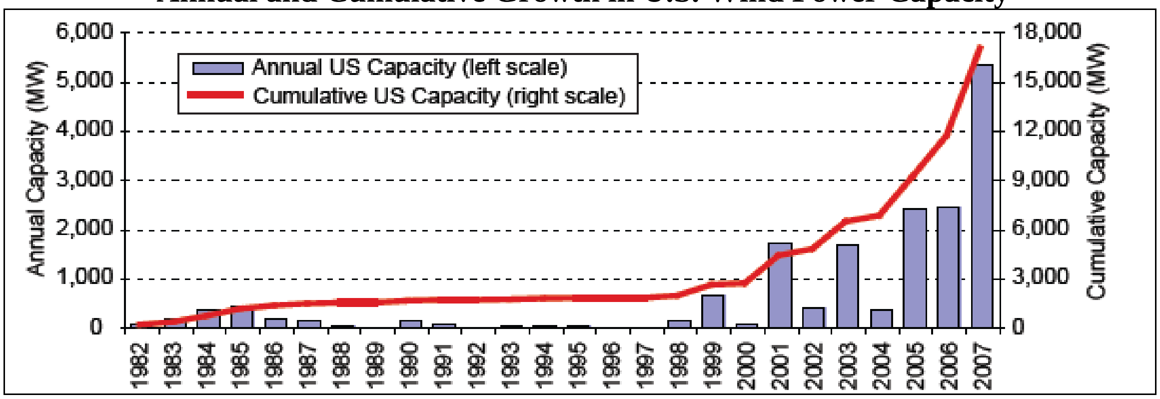
The first step in developing a strategy and policies for utilizing renewable energy resources is determining technical feasibility. That is, are the resources available and accessible, and are there technologies and infrastructure that allow harvesting these resources? Several organizations have conducted studies and compiled data on renewable energy resources that have potential applications for South Carolina (see S.C. Energy Office website at www.energy.sc.gov/index.aspx?m=6). Wind energy is a major component of most states' strategies to develop renewable resources for electricity generation. With cost reductions and performance improvements over the last 21 years, wind could be a significant energy resource for South Carolina.

The report presented here gives an introduction to wind-generated power in the U.S. and provides the results of a feasibility analysis conducted by the University of South Carolina's Institute for Public Service & Policy Research and the Department of Geography that uses Geographic Information System (GIS) techniques to investigate wind as a resource for electric power generation in South Carolina. Specifically, this research focuses on the availability and accessibility of wind as an energy resource.

Introduction to Wind-generated Power

The U.S. wind power capacity increased by 46% in 2007 according to the U.S. Department of Energy (2008). The U.S. wind power market continued its rapid expansion with a record breaking year in 2007, with 5,239 megawatts (MW) of new capacity added, for a cumulative total of 16,904 MW (Figure 1). This growth translates to approximately $9 billion (in real 2007 dollars) invested in wind project installation in 2007, for a cumulative total of nearly $18 billion since the 1980s.

Figure 1.
Annual and Cumulative Growth in U.S. Wind Power Capacity

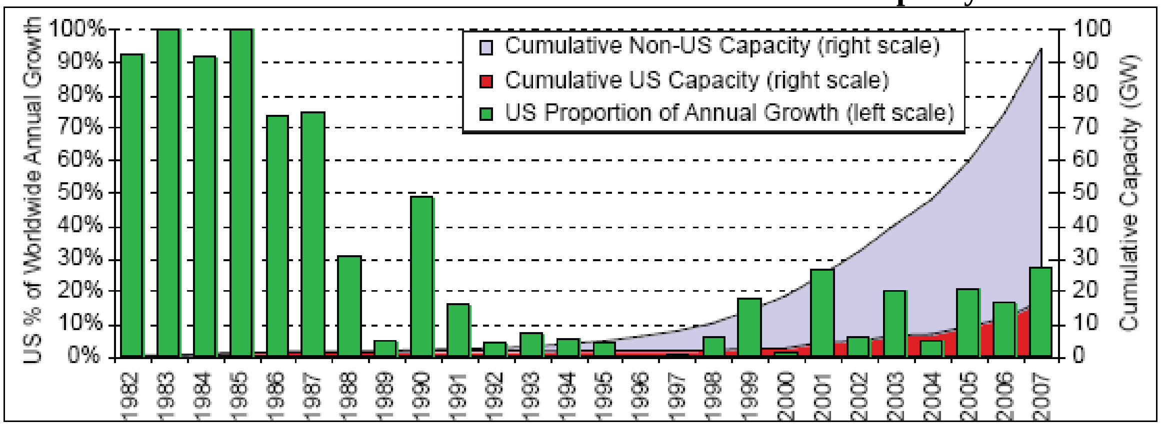


Source: Retrieved October 27, 2008 from the American Wind Energy Association at www.awea.org.

This increase in capacity for 2007 was the largest year on record in the U.S., and more than twice the previous record in 2006. This growth was facilitated by federal tax incentives, state renewable energy standards (RPSs) and incentives, concern about global climate change, and continued uncertainty for the future cost and liabilities of conventional natural gas and coal facilities. Also, wind power was the second-largest new resource added to the U.S. electrical grid capacity for the third consecutive year, behind the 7,500 MW of new natural gas plants, but ahead of new coal at 1,400 MW. New wind generation facilities contributed approximately 35% of new capacity added to the U.S. electrical grid in 2007, compared to 19% in 2006 (USDOE, 2008).

Figure 2 shows that approximately 20,000 MW of wind capacity were added in 2007, an increase of approximately 15,000 MW in 2006, for a cumulative total of approximately 94,000 MW (or 94 gigawatts - GW) worldwide. The U.S. led the world in wind capacity additions, with approximately 27% of the worldwide market. China, Spain, and Germany complete the top four leaders. The U.S. ended the year with 18% of the worldwide cumulative installed wind capacity, ranked second behind Germany. So far this decade (i.e., over the past eight years), wind power capacity has grown on average by 27% per year in the U.S., equivalent to the same growth rate worldwide.

Figure 2.
Annual and Cumulative Growth
United States Percent of Worldwide Wind Power Capacity



(Source: The Earth Policy Institute, BTM Consult, and American Wind Energy Association available at www.awea.org.

In Europe, 200 MW of wind powered energy was installed offshore in 2007, usually in water depths of 25 meters or less; but, as Table 1 and Figure 3 show, all wind projects built in the U.S. were sited on land **(**defined here as individual turbines or projects that exceed 50 kilowatts (kW) in size)**.** There have been no wind power projects developed in South Carolina. However, there is interest in offshore wind in several parts of the United States because of the proximity of offshore wind resources to large population centers, permitting constraints and transmission limitations for land-based projects, as well as advances in technology and potentially superior capacity for offshore facilities (USDOE, 2008). Table 2 provides a listing of offshore project proposals in the U.S. at the end of 2007. Note that South Carolina is not found in the list.

Table 1.
Top Twenty States Wind Power Rankings

Incremental Capacity (2007, MW)		Cumulative Capacity (end of 2007, MW)		Estimated Percentage of In-State Generation	
Texas	1,708	Texas	4,446	Minnesota	7.5%
Colorado	776	California	2,439	Iowa	7.5%
Illinois	592	Minnesota	1,298	Colorado	6.1%
Oregon	444	Iowa	1,271	South Dakota	6.0%
Minnesota	403	Washington	1,163	Oregon	4.4%
Washington	345	Colorado	1,067	New Mexico	4.0%
Iowa	341	Oregon	882	North Dakota	3.8%
North Dakota	167	Illinois	699	Oklahoma	3.0%
Oklahoma	155	Oklahoma	689	Texas	3.0%
Pennsylvania	115	New Mexico	496	Washington	2.8%
California	63	New York	425	California	2.8%
Missouri	57	Kansas	364	Kansas	2.3%
New York	55	North Dakota	345	Hawaii	2.3%
South Dakota	54	Pennsylvania	294	Montana	1.9%
Maine	33	Wyoming	288	Wyoming	1.7%
Hawaii	21	Montana	147	Idaho	1.5%
Massachusetts	2	South Dakota	98	Illinois	0.8%
Montana	2	Idaho	75	Maine	0.8%
		Nebraska	73	New York	0.7%
		West Virginia	66	Nebraska	0.7%
Rest of U.S.	0	*Rest of U.S.*	277	*Rest of U.S.*	0.05%
TOTAL	**5,329**	**TOTAL**	**16,904**	**TOTAL**	**1.1%**

Source: U.S. Department of Energy.

Figure 3.
The Size and Location of Wind Power Development in the U.S.

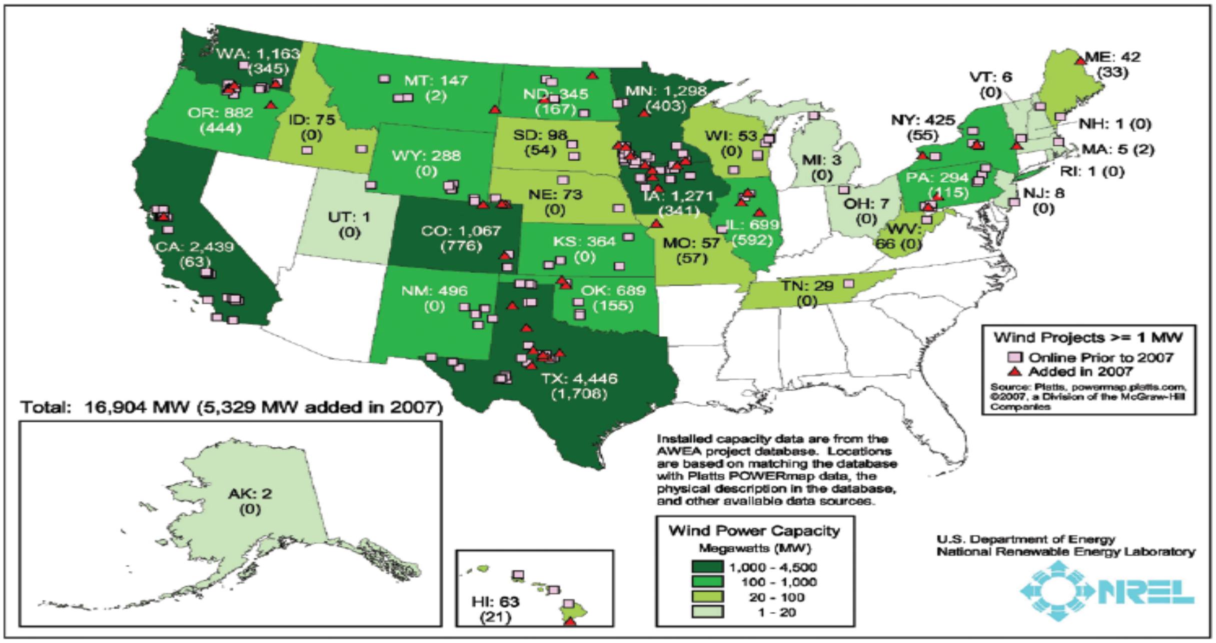


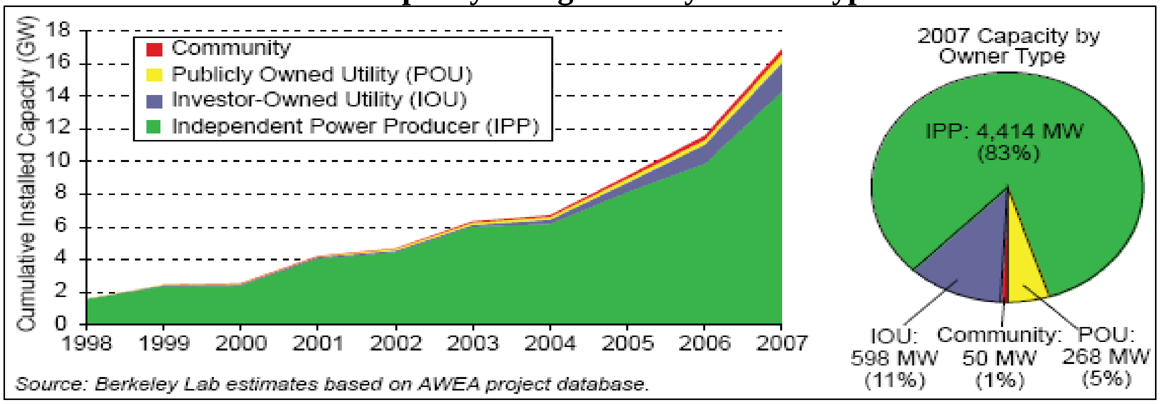
Table 2.
Proposed Offshore Wind Capacity

State	Proposed Offshore Wind Capacity
Massachusetts	783 MW
Delaware	450 MW
New Jersey	350 MW
New York	160 MW
Texas	150 MW
Ohio	20 MW
Georgia	10 MW
TOTAL	**1,923 MW**

Source: National Renewable Energy Laboratory available at www.nrel.gov.

The increased acceptance of wind power is shown in Figure 4 with electric utilities expressing greater interest in owning wind assets. Private independent power producers (IPPs) continued to dominate the wind industry in 2007 with 83% of all new capacity.

Figure 4.
Cumulative and Annual (2007)
Wind Capacity Categorized by Owner Type



Source: U.S. Department of Energy, 2008.

Unfortunately, relatively little investment has been made in the creation of new transmission lines over the past 15 to 21 years, and the lack of transmission access and investment are major barriers to wind development in the U.S. (USDOE, 2008). Development of new transmission capabilities is important for wind power development because of the “locational” dependence and distance from load centers for many wind turbine facilities. Furthermore, wind projects require shorter time for development than the time often required to develop new transmission lines, and new transmission lines intended only to serve wind turbine facilities may be underutilized (USDOE, 2008). However, there have been several recent policy developments by the USDOE and the Federal Energy Regulatory Commission (FERC) that potentially will encourage greater transmission investment.

South Carolina Offshore Wind Power Estimation

This section summarizes the logic, data, methods, and results of estimating offshore wind power potential for South Carolina through a GIS analysis.

Geospatial Data Analyzed in the Geographic Information System

Four variables were used to determine the maximum theoretical potential for offshore wind power in South Carolina. The four variables considered were:

- Wind speed;
- Water depth;
- Distance to South Carolina shoreline; and,
- Distance to navigable waterways.

Table 3 summarizes the full set of data collected and used for the suitability analysis.

Table 3.
GIS Data Used to Estimate the Maximum Offshore Wind Power for South Carolina

Data	Source	Data Format	Description
Wind Speed	AWS Truewind	Raster	Wind speed data at vertical height of 50 meters, spatial resolution 200 x 200 m.
Bathymetric Data	NOAA	Raster	Generated from NOAA Coastal Relief Gridded data model, with spatial resolution of 3 arcs second.
S.C Shoreline Data	NOAA	Vector	Downloaded from NOAA Coastal Service Center.
U.S. Waterway Data	USACE	Vector	Downloaded from Navigation Data Center.

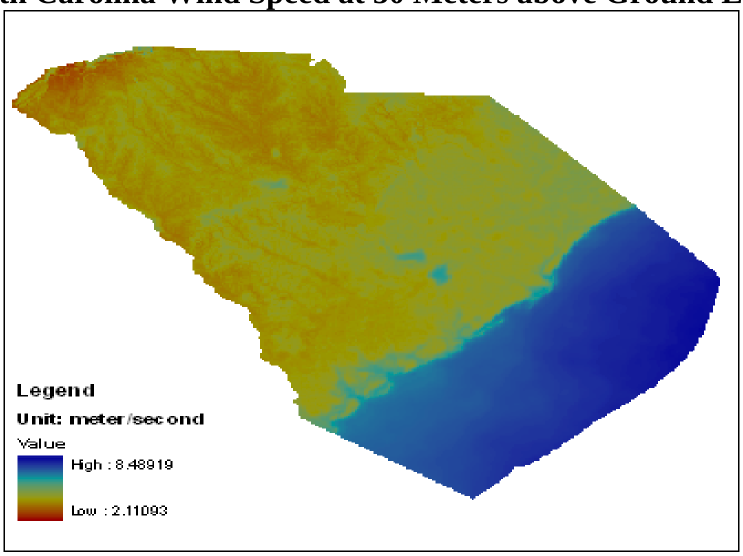
Note: "Vector graphics is the use of geometrical primitives such as points, lines, curves, and shapes or polygon(s), which are all based upon mathematical equations, to represent images in computer graphics. Vector graphics formats are complementary to raster graphics, which is the representation of images as an array of pixels, as it is typically used for the representation of photographic images." Retrieved November 6, 2008 from http://en.wikipedia.org/wiki/Vector_graphics.

Wind Speed Data

Wind power is the conversion of wind energy into a useful form, such as electricity, using wind turbines. Wind power generation is directly related to wind speed. Theoretically, the power available varies with the cube (the third power) of the average wind speed.

South Carolina has very good offshore wind resources. The average South Carolina wind speed at a vertical height of 50 meters above ground level is shown in Figure 5. The wind speed data were produced by AWS Truewind, LLC, at a spatial resolution of 200 x 200 meters. Most offshore areas have a wind speed larger than 6.5 m/s.

Figure 5.
South Carolina Wind Speed at 50 Meters above Ground Level



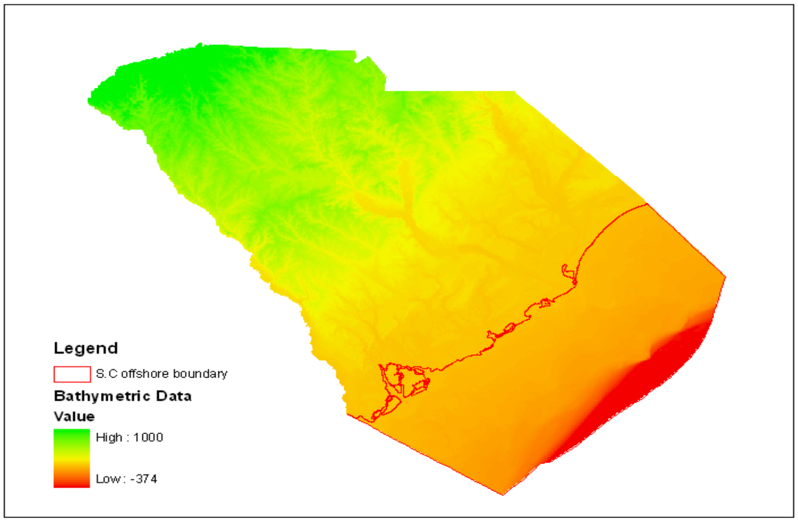
Source: AWS Truewind, LLC.

Water Depth (Bathymetric) Data

There is no direct relationship between wind power generation and water depth. But, wind turbines can only be located in certain water depths. Most wind turbines have a maximum water depth index.

The NOAA Geophysical Data Center created a Coastal Relief Gridded Database which provides bathymetric data of the United States coastal zone. The bathymetric data used in our analysis were extracted from this database. The offshore bathymetry of South Carolina is shown in Figure 6.

Figure 6.
Bathymetry of South Carolina
(In meters)



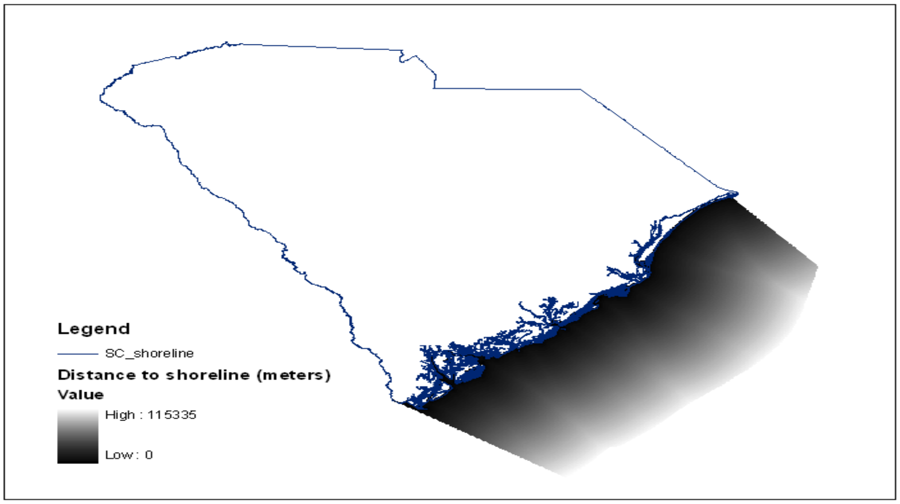
Source: NOAA Geophysical Data Center created a Coastal Relief Gridded Database.

Distance to Shoreline Data

The distance to shoreline is also an important factor for offshore wind power generation. From an aesthetics point of view, the wind turbine should not be installed near the shoreline. The noise and visual intrusion require the wind farm to be installed at certain distances from the shoreline.

The South Carolina shoreline data were obtained from the NOAA Coastal Services Center. South Carolina's shoreline and distance (in meters) to the shoreline are shown in Figure 7.

Figure 7.
South Carolina Shoreline and the Distance to the Shoreline (In meters)

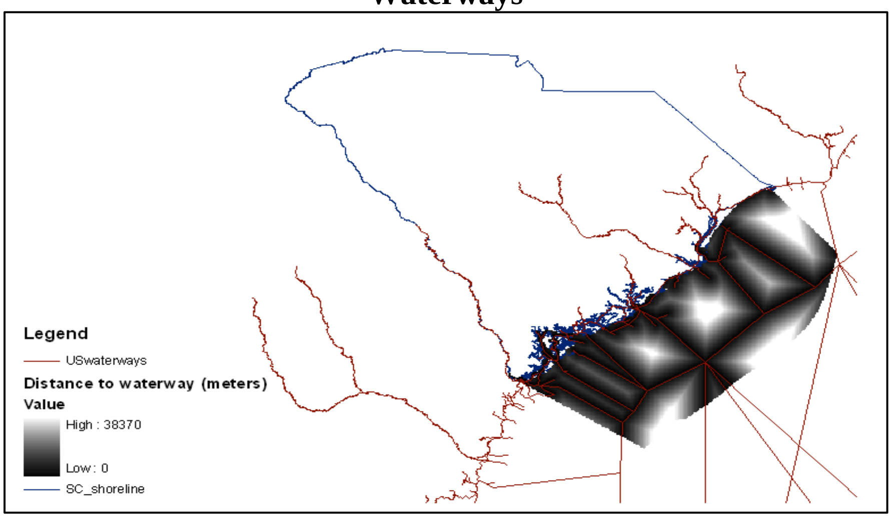


Source: NOAA Coastal Services Center.

Distance to Navigable Waterway Data

For safety and aesthetics considerations, the wind farm should also be installed at a practical distance from major navigable waterways. The U.S navigable waterway data were obtained from the United States Army Corps of Engineers Navigation Data Center. The major navigable waterways offshore and the distance from these waterways are shown in Figure 8.

Figure 8.
Major Navigable Waterways Offshore South Carolina and the Distance to Waterways

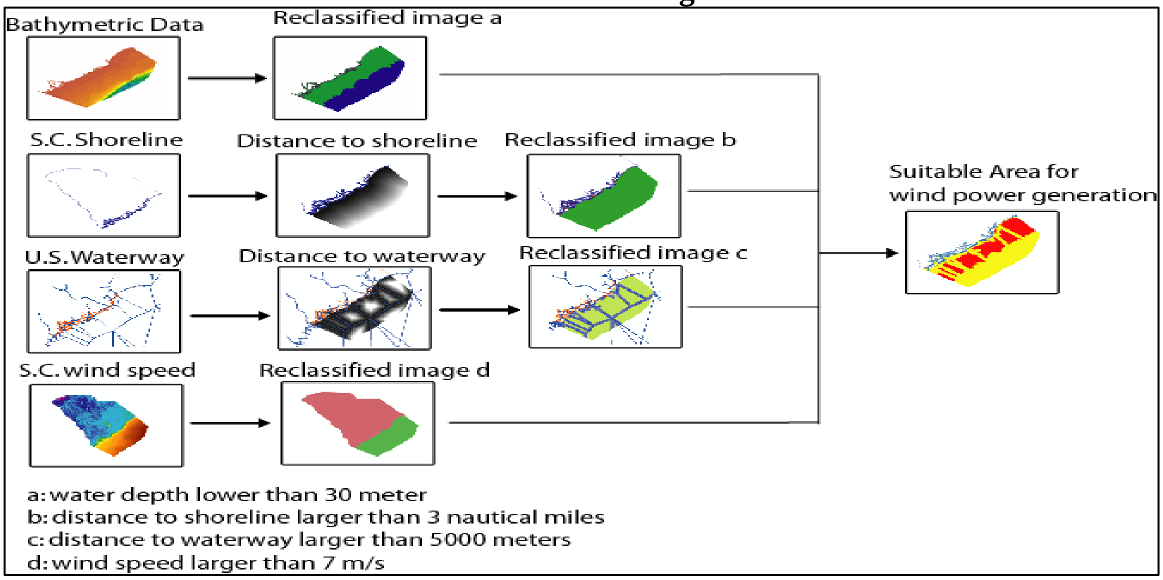


Source: Army Corps of Engineers Navigation Data Center.

Criteria Refinement

A GIS pass/fail suitability model was used to determine the appropriate geographic area for offshore wind farm installation. The GIS data flow is shown in Figure 9. The process was implemented using ArcObjects programming (Environmental Systems Research Institute, Inc.).

Figure 9.
GIS Data Processing Flowchart



Wind Speed Criteria

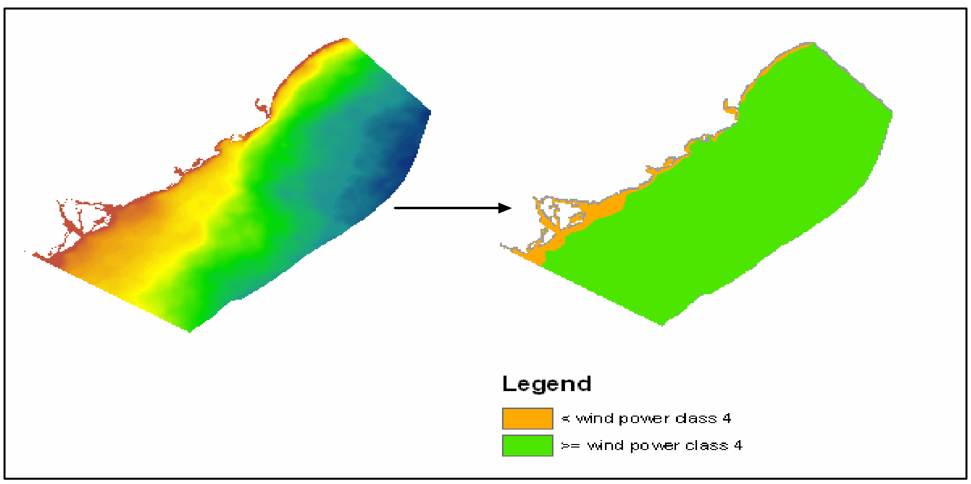
Wind resources can be used by both large commercial wind turbines for utility applications or by small wind turbines for on-site commercial or personal energy generation. As a renewable resource, wind is classified according to wind power classes, which are based on typical wind speeds, ranging from Class 1 (the lowest) to Class 7 (the highest). The relationship between wind power density and wind speed is summarized in Table 4. In general, Class 4 winds and above (i.e., wind speeds $\geq$ 7 m/s), are considered good wind resources for power generation, especially when using large turbines located 50 meters above ground level (TRC Environmental Corporation, 2006). Therefore, Class 4 wind power and above were defined as appropriate wind resources for wind power generation. The original offshore wind speed data were reclassified in the GIS. The South Carolina geographic area with wind power $\geq$ Class 4 is shown in Figure 10.

Table 4.
Classes of Wind Power Density at 10 and 50 Meters above Ground Level

Classes of Wind Power Density at 10 m and 50 m above ground level				
	10 m (33 ft)		50 m (164 ft)	
Wind Power	Wind Power Density (W/m2)	Speed m/s (mph)	Wind Power Density (W/m2)	Speed m/s (mph)
1	<100	<4.4 (9.8)	<200	<5.6 (12.5)
2	100 - 150	4.4 (9.8)/5.1 (11.5)	200 - 300	5.6 (12.5)/6.4 (14.3)
3	150 - 200	5.1 (11.5)/5.6 (12.5)	300 - 400	6.4 (14.3)/7.0 (15.7)
4	200 - 250	5.6 (12.5)/6.0 (13.4)	400 - 500	7.0 (15.7)/7.5 (16.8)
5	250 - 300	6.0 (13.4)/6.4 (14.3)	500 - 600	7.5 (16.8)/8.0 (17.9)
6	300 - 400	6.4 (14.3)/7.0 (15.7)	600 - 800	8.0 (17.9)/8.8 (19.7)
7	>400	>7.0 (15.7)	>800	>8.8 (19.7)

Source: Data from NREL.

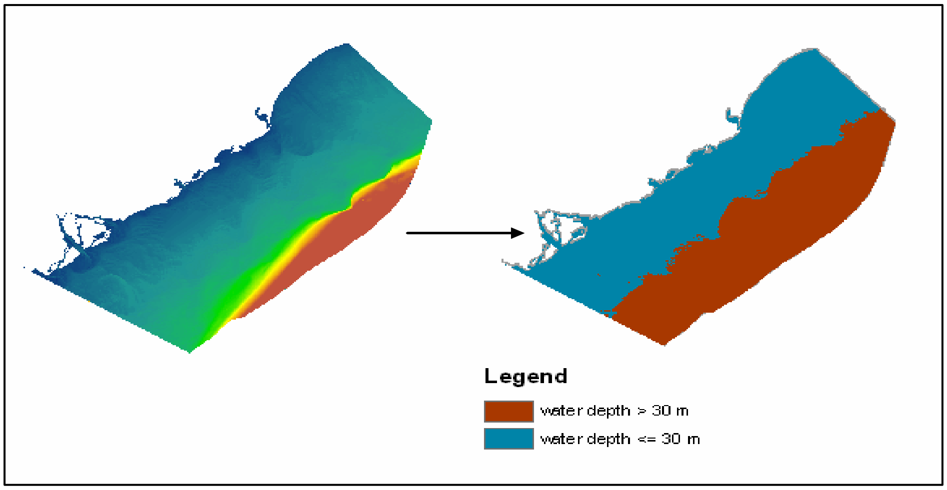
Figure 10.
Areas Offshore South Carolina with Wind Power Classes $\geq$ Class 4



Water Depth Criteria

Several studies have identified the appropriate water depth for wind power generation. Bulpitt (2006) states that 20 meters is currently the depth limit of conventional wind turbine platform construction techniques. However, the TRC Environmental Corporation (2006) reports 30 meters is an appropriate water depth for wind power generation. For purposes of this article, 30 meters was adopted as the appropriate threshold for wind power generation. Figure 11 shows the geographic areas with water depths $\leq$ 30 meters.

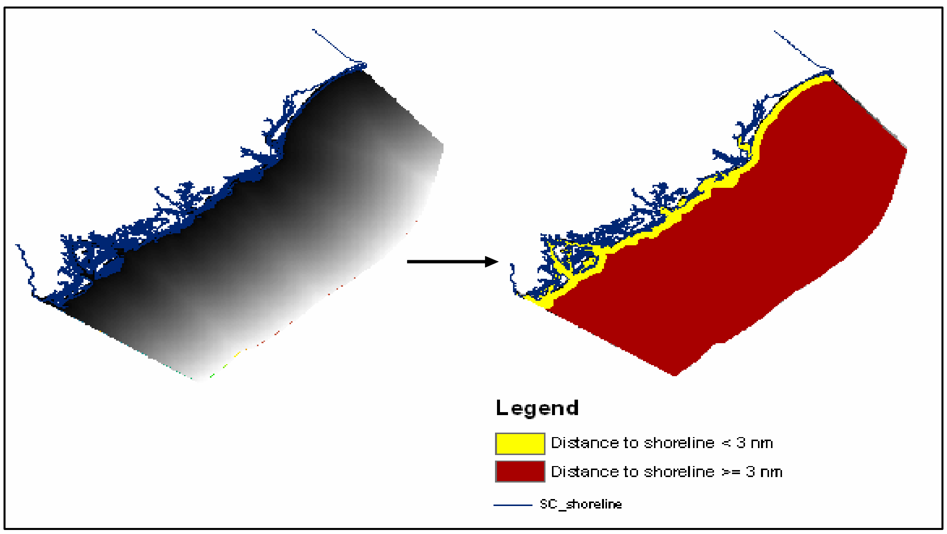
Figure 11.
Offshore South Carolina Water Depths ≤ 30 Meters



Distance to Shoreline Criteria

Mufson and Eilperin (2006) reported that a Texas wind farm project was approved and that the wind farm would be located a minimum distance of three miles offshore from Padre Island and south of Baffin Bay, TX. Also, according to the U.S. Submerged Lands Act, the ownership of the first three miles of a state's coastal submerged lands was transferred to the federal government. Therefore, three nautical miles (nm) was adopted as the distance from shoreline threshold value for wind power generation (Figure 12).

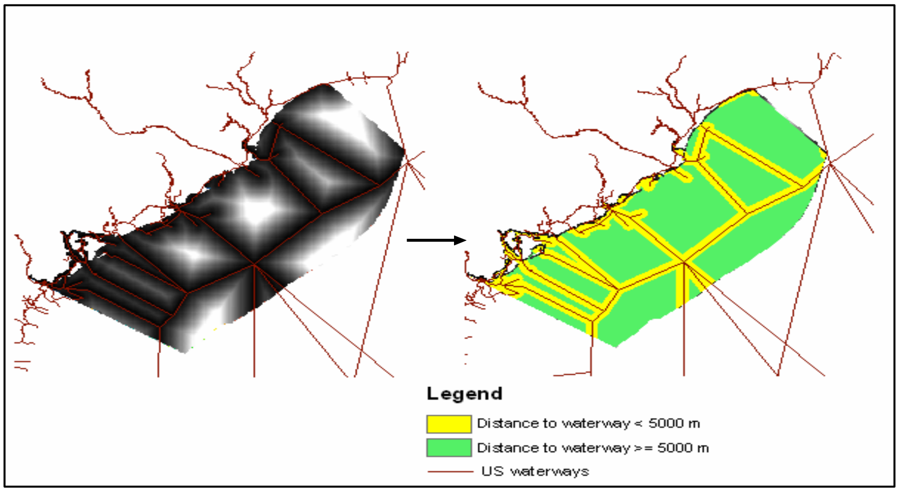
Figure 12.
Offshore Areas ≥ 3 nm Miles



Distance to Navigable Waterway Criteria

Distance to U.S. waterways is another important criterion for offshore wind power generation. From safety and aesthetics considerations, wind farms should be built at certain distance to the waterway. For our analysis, five km were used as the distance threshold. Offshore areas $\geq$ 5 nm from a navigable waterway are shown in Figure 13.

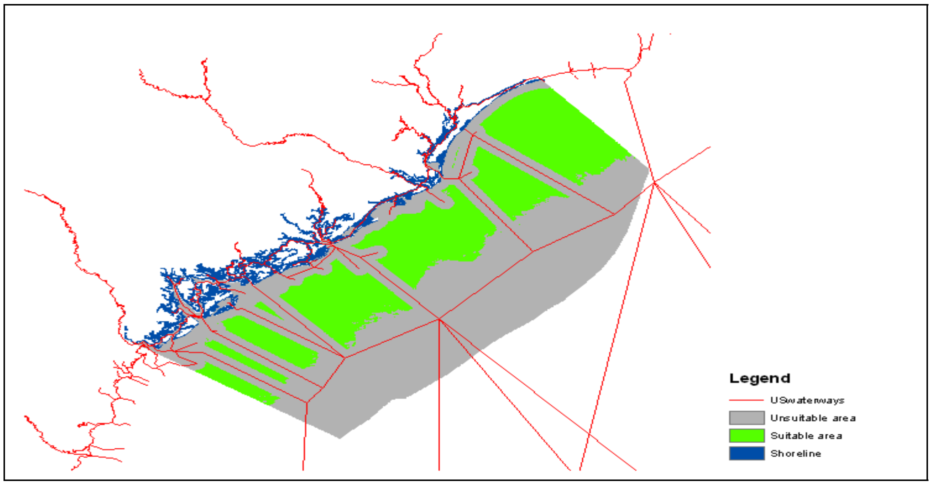
Figure 13.
Offshore Areas $\geq$ 5000 m from a Navigable Waterway



Areas Suitable for Offshore Wind Power Generation

Geographic areas that satisfied the four criteria may be considered good candidates for offshore wind power generation in South Carolina. These areas are shown in Figure 14.

Figure 14.
Suitable Areas for Offshore Wind Power Generation



Specific Suitability Categories for Offshore Wind Power Generation

For purposes of this assessment, the suitable areas for wind power generation were grouped into specific categories so that information compiled for analysis would be in a format compatible with other wind power studies. Each category was characterized by wind power class, water depth, and distance to shoreline. Wind resources categories were: wind power < Class 4, wind power Class 4, wind power Class 5, and wind power ≥ Class 6. Water depth categories were shallow (<30 m), transitional (30 – 60 m), and deep (60 – 100 m). Distance to shoreline categories were near (0 – 3 nm), intermediate (3 – 10 nm), and far (10 – 50 nm).

The process was implemented using ArcObjects programming in the GIS. The work flowchart is shown in Figure 15. The final category map is shown in Figure 16.

Figure 15.
Flowchart for Summarizing the Information by Category

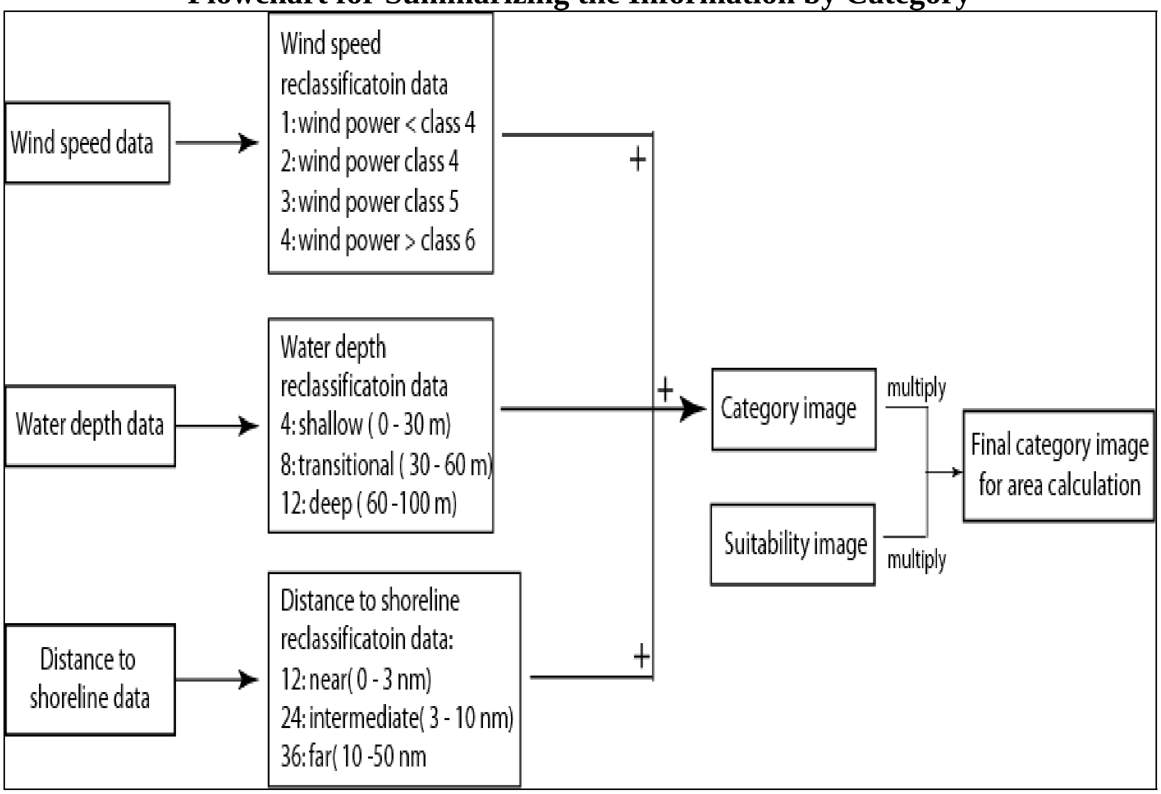
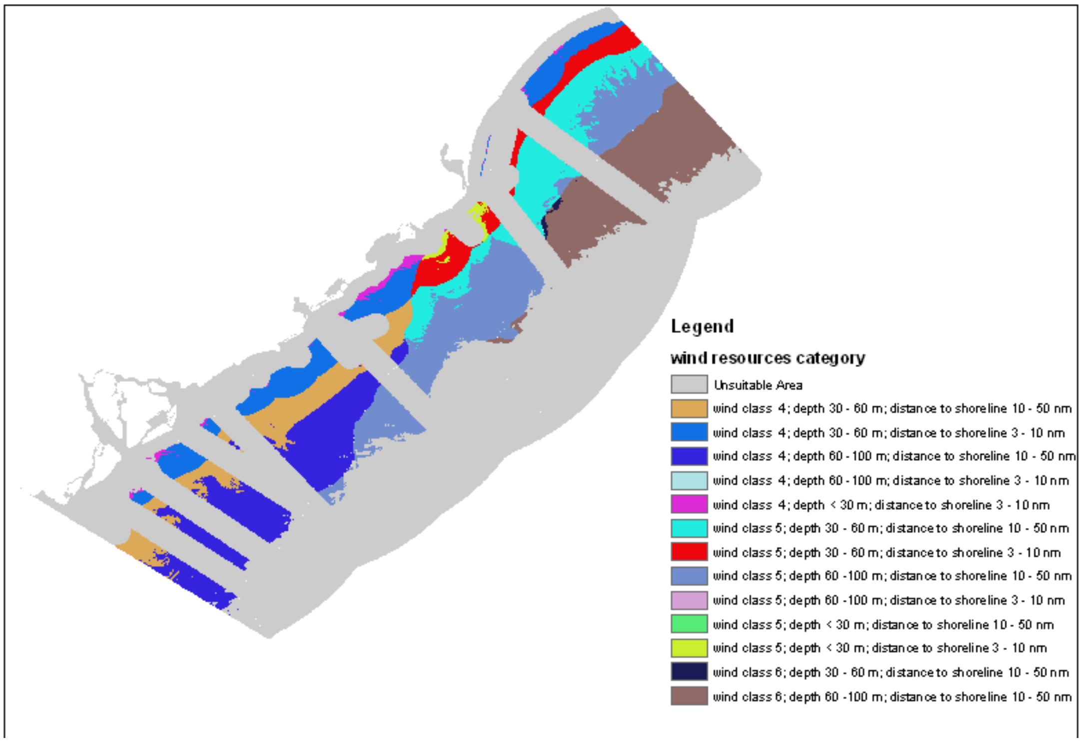


Figure 16.

Offshore Wind Resource Areas by Category



Area Calculation for Different Wind Resource Categories

As previously discussed, wind power generation is directly related to wind speed, and theoretically the power available at a given wind speed varies with the cube (the third power) of the average wind speed. Wind farm construction is also related to the distance to the shoreline and water depth. Table 5 shows the total area in square kilometers for each wind resource category.

Table 5.
Total Area for Different Wind Power Categories
(Unit: km^2)

Wind Class	Class 4	Class 4	Class 4	Class 4	Class 4	Class 4	Class 4	Class 4	Class 4
Distance from Shore	0 - 3 nm	0 - 3 nm	0 - 3 nm	3 - 10 nm	3 - 10 nm	3 - 10 nm	10 - 50 nm	10 - 50 nm	10 - 50 nm
Depth Category	Shallow	Transitional	Deep	Shallow	Transitional	Deep	Shallow	Transitional	Deep
Area (km^2)	0	0	0	125	1268	0	0	1063	1963
Wind Class	Class 5	Class 5	Class 5	Class 5	Class 5	Class 5	Class 5	Class 5	Class 5
Distance from Shore	0 - 3 nm	0 - 3 nm	0 - 3 nm	3 - 10 nm	3 - 10 nm	3 - 10 nm	10 - 50 nm	10 - 50 nm	10 - 50 nm
Depth Category	Shallow	Transitional	Deep	Shallow	Transitional	Deep	Shallow	Transitional	Deep
Area (km^2)	0	0	0	86	685	0	3	1450	2710
Wind Class	Class 6	Class 6	Class 6	Class 6	Class 6	Class 6	Class 6	Class 6	Class 6
Distance from Shore	0 - 3 nm	0 - 3 nm	0 - 3 nm	3 - 10 nm	3 - 10 nm	3 - 10 nm	10 - 50 nm	10 - 50 nm	10 - 50 nm
Depth Category	Shallow	Transitional	Deep	Shallow	Transitional	Deep	Shallow	Transitional	Deep
Area (km^2)	0	0	0	0	0	0	0	29	2000

Calculation of Wind Power Feasible Capacity and Feasible Generation

"Feasible capacity" refers to the maximum potential that might reasonably be expected to be implemented. In the research, the feasible capacity was calculated using the equation:

Feasible Capacity (MW) Calculation = Area (km^2)* Generation Potential Factor (MW/ km^2)

"Generation potential factor" refers to how much wind energy can be generated for each square kilometer. The analysis in this article assumes that 5 MW/ km^2 of turbines are installed per square kilometer in areas determined to be windy. This is a standard assumption for wind power calculations.

"Feasible generation" refers to the total feasible energy in gigawatt hours (GWh) that can be generated in one year. It was calculated using the equation:

Feasible Generation (GWh) = Feasible Capacity (MW) * Capacity Factor * 24*365/1000

"Capacity factor" is simply the wind turbine's actual energy output for the year divided by the energy output if the machine operated at its rated power output for the entire year. A reasonable capacity factor would be 0.25 - 0.30. A very good factor would be 0.40. Capacity factor is very sensitive to the average wind speed. Table 6 illustrates the capacity factors for each wind power class, the total feasible capacity, and the total feasible generation for each wind resource category. In summary, the estimated total feasible generation for South Carolina offshore wind resources is 169,252 GWh.

Table 6.
South Carolina Total Feasible Capacity and Feasible Generation of Offshore Wind Power Resources

Wind Class 4	Class 4	Class 4	Class 4	Class 4	Class 4	Class 4	Class 4	Class 4	Class 4	Total
Generation potential (MW/km2)	5	5	5	5	5	5	5	5	5	
Capacity factor	30%	30%	30%	30%	30%	30%	30%	30%	30%	
Feasible Capacity (MW)	0	0	0	625	6340	0	0	5315	9815	
Feasible Generation (GWh)	0	0	0	1642.5	16661.52	0	0	13967.82	25793.82	58065.66
Wind Class 5	Class 5	Class 5	Class 5	Class 5	Class 5	Class 5	Class 5	Class 5	Class 5	
Generation potential (MW/km2)	5	5	5	5	5	5	5	5	5	
Capacity factor	35%	35%	35%	35%	35%	35%	35%	35%	35%	
Feasible Capacity (MW)	0	0	0	430	3425	0	15	7250	13550	
Feasible Generation (GWh)	0	0	0	1318.38	10501.05	0	45.99	22228.5	41544.3	75638.22
Wind Class 6	Class 6	Class 6	Class 6	Class 6	Class 6	Class 6	Class 6	Class 6	Class 6	
Generation potential (MW/km2)	5	5	5	5	5	5	5	5	5	
Capacity factor	40%	40%	40%	40%	40%	40%	40%	40%	40%	
Feasible Capacity (MW)	0	0	0	0	0	0	0	145	10000	
Feasible Generation (GWh)	0	0	0	0	0	0	0	508.08	35040	35548.08

New windmill farm at the mouth of Spanish Fork Canyon near Spanish Fork, Utah.

This section summarizes the logic, data, methods, and results of estimating onshore wind power for South Carolina.

Geospatial Data Analyzed in the Geographic Information System

Six variables were used to determine the maximum theoretical potential of onshore wind power for South Carolina. The six variables considered were:

- Distance to airports;
- Distance to roads;
- Distance to railroads;
- Distance to utilities;
- Wind speed; and,
- Land cover.

Table 7 summarizes the full set of data collected and used for the suitability analysis.

Table 7.
GIS Data Used to Estimate the Maximum Onshore Wind Power for South Carolina

Data	Sources	Format	Description
Land cover - GAP	SCDNR	Raster	Statewide land cover map, including overall 27 land cover classes
S.C Wind Speed Data	AWS Truewind	Raster	Wind speed at vertical height of 50 m, spatial resolution is 200 x 200 m
Airport Data	USC GIS Data Server	Vector	South Carolina airport data
Road	USC GIS Data Server	Vector	South Carolina road data
Railroad	USC GIS Data Server	Vector	South Carolina railroad data
Utility	GeoComm.com	Vector	South Carolina utility line data

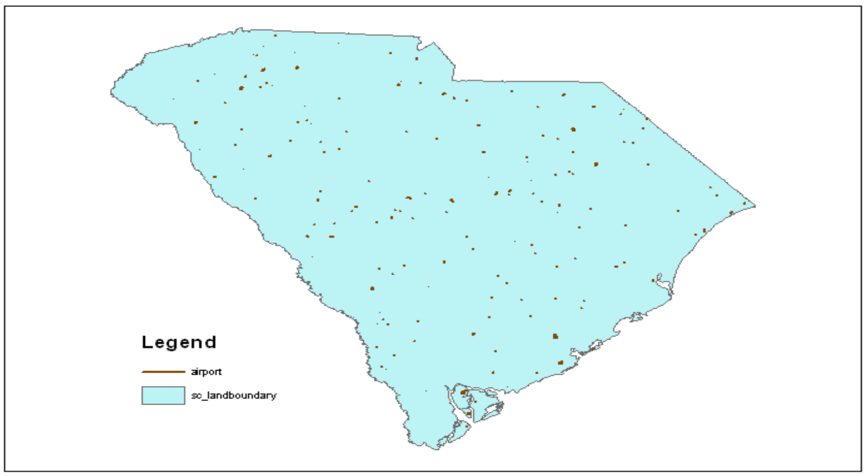
Wind Speed Data

The onshore area of South Carolina does not have very good wind resources. The wind speed map of South Carolina at a vertical height of 50 meters above ground level is shown above in Figure 5. As shown above (Table 7), the wind speed data were produced by AWS Truewind, LLC, at a spatial resolution of 200 x 200 meters.

Airport Data

It is not wise to build a wind turbine in the vicinity of an airport. All the airports in South Carolina are displayed in Figure 17. The data were obtained from the USC GIS Data Server in vector format, and polyline geometry. (See http://www.cas.sc.edu/gis/dataindex.html.)

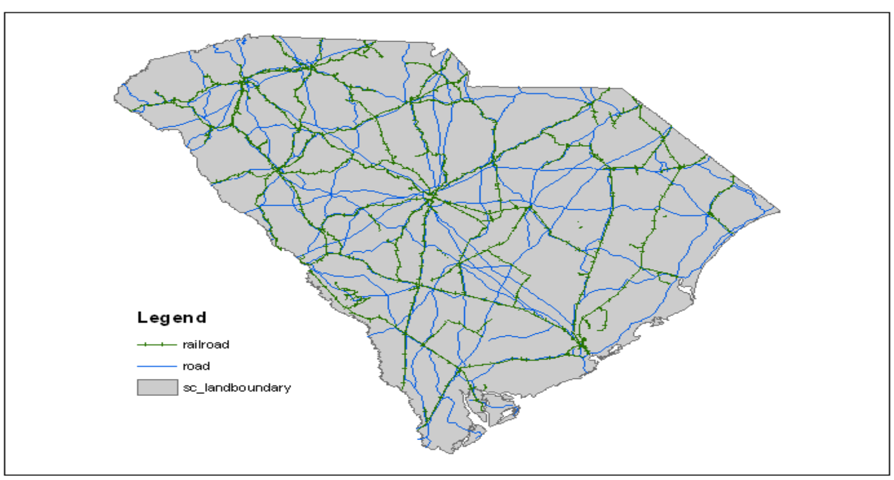
Figure 17.
Airports in South Carolina



Road and Railroad Data

Wind turbines should be located a certain distance away from major roads and railroads. All the major roads and the railroads in South Carolina are displayed in Figure 18**.** The data were obtained from the USC GIS Data Server in vector format and polyline geometry.

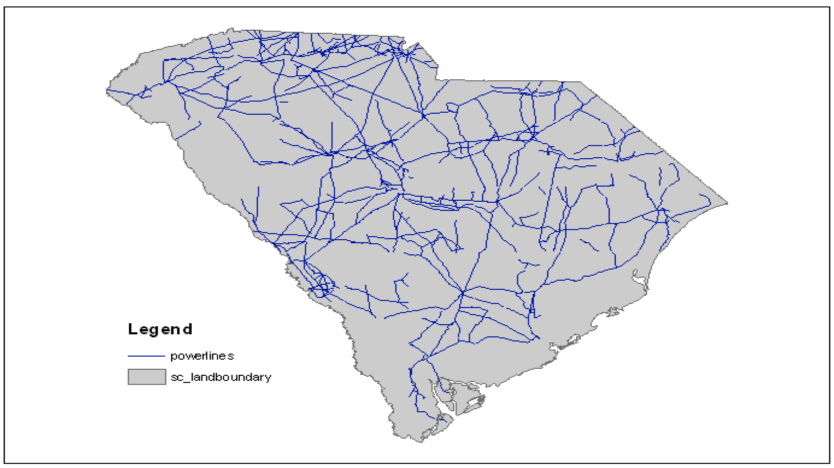
Figure 18.
South Carolina Roads and Railroads



Transmission Powerline Data

Locating wind turbines extremely close to major utility transmission lines is not recommended. However, it is wise to locate the wind turbine as close as practically feasible to the transmission line so that energy from the wind turbine can be efficiently connected to the existing power transmission grid. The major powerlines in South Carolina in 1990 are shown in Figure 19**.** The data were provided by the GeoCommunity website, originally derived from USGS digital line graphs (DLG) data.

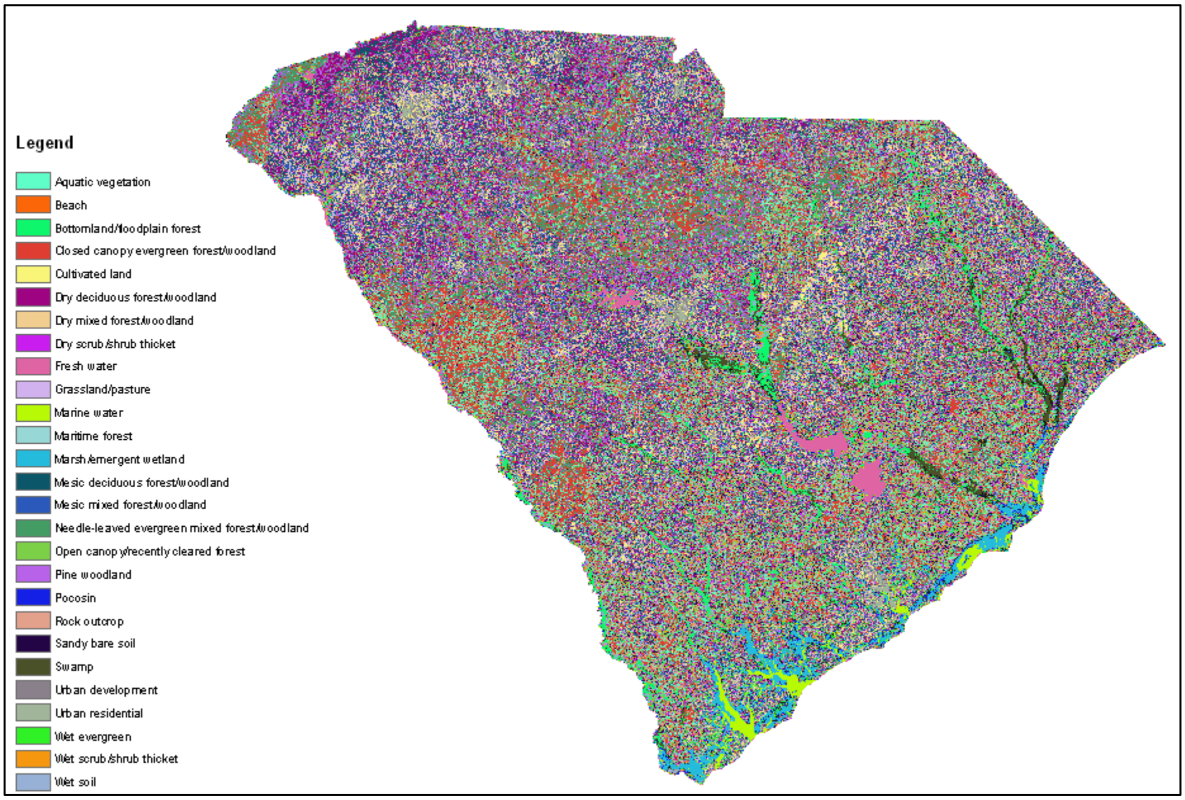
Figure 19.
South Carolina Powerlines in 1990



Land Cover Data

The type of land cover present can have a dramatic effect on whether or not a parcel of land is suitable for the placement of wind turbines. For example, it is highly unlikely that wind turbines will be located on highly-protected wetlands. The land cover of South Carolina in 19 categories is shown in Figure 20. The data were extracted from the South Carolina Department of Natural Resources GAP data clearinghouse. The land cover data are in raster format and the spatial resolution is 30 x 30 meters.

Figure 20.
Land Cover of South Carolina in 29 Classes



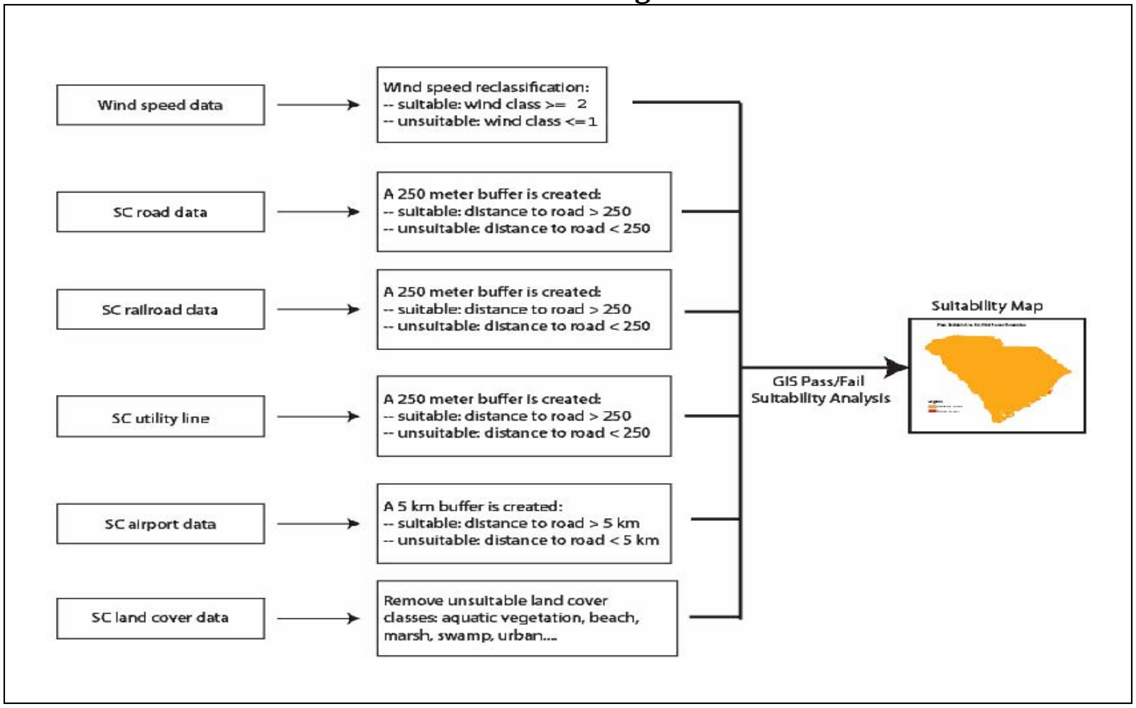
Source: S.C. Department of Natural Resources GAP Analysis Project.

Criteria Refinement

A GIS pass/fail suitability model was used to determine the appropriate geographic area for onshore wind farm installation. The GIS data flow is shown in Figure 21. The process was implemented using ArcObjects programming. The following criteria were used during the processing:

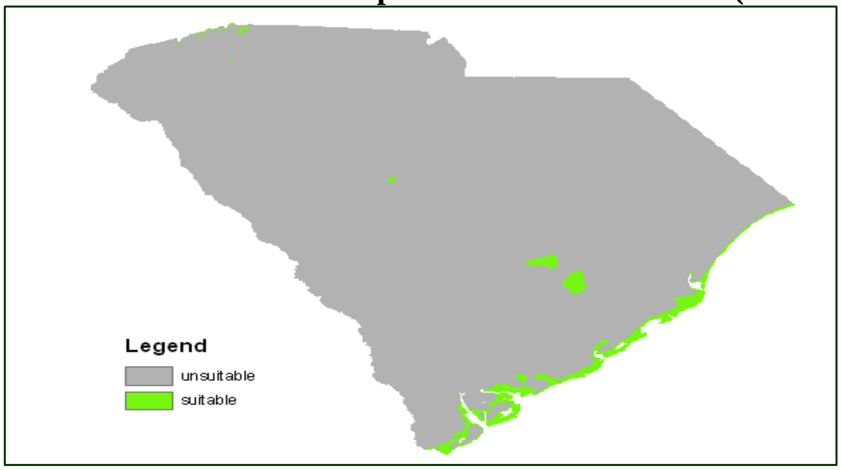
- Distance to road $\geq$ 250 meters;
- Distance to railroad $\geq$ 250 meters;
- Distance to utility lines $\geq$ 250 meters;
- Distance to airport $\geq$ 5 km; and,
- Wind speed $\geq$ wind power Class 2 (5.6 m/s).
- Unsuitable land cover classes:
    - Aquatic vegetation,
    - Beach,
    - Bottomland/floodplain forest,
    - Marsh/emergent wetland,
    - Pocosin (a wetland with deep, acidic, sandy, peat soils),
    - Swamp,
    - Urban development, and
    - Urban residential.

Figure 21.
GIS Data Processing Flowchart



Regarding the wind speed criterion, in the previous section of this article, it was documented that there are very powerful wind resources offshore of South Carolina which can drive wind turbines. Unfortunately, this is not the case over mainland South Carolina. For mainland South Carolina, it was necessary to lower the acceptable wind power class to Class 2 (> 5.6 m/s) which is still suitable for operating wind turbines. Notice that most of the acceptable areas are associated with mountain ridges, large lakes, and coastal shoreline areas (Figure 22).

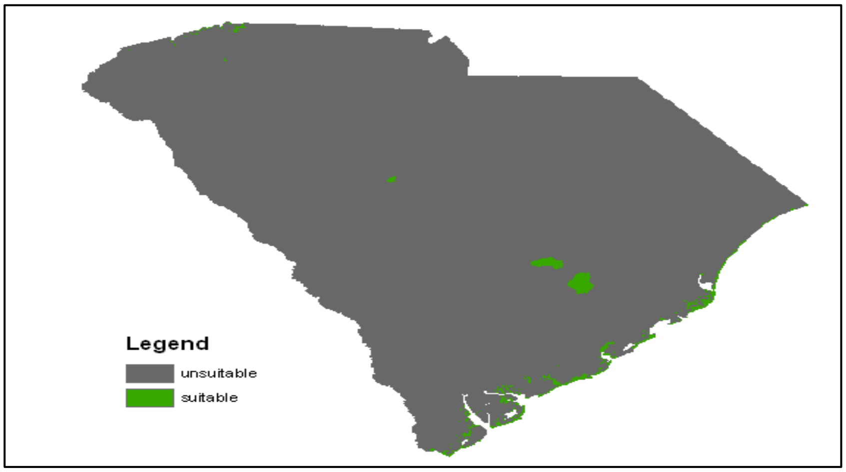
Figure 22.
The Relatively Small Mainland Geographic Area in
South Carolina with Wind Speeds in Excess of 5.6 m/s (Class 2)



Areas Suitable for Onshore (Mainland) Wind Power Generation

Geographic areas that satisfied the six criteria may be considered good candidates for onshore wind power generation in South Carolina. The final suitability map is shown in Figure 23.

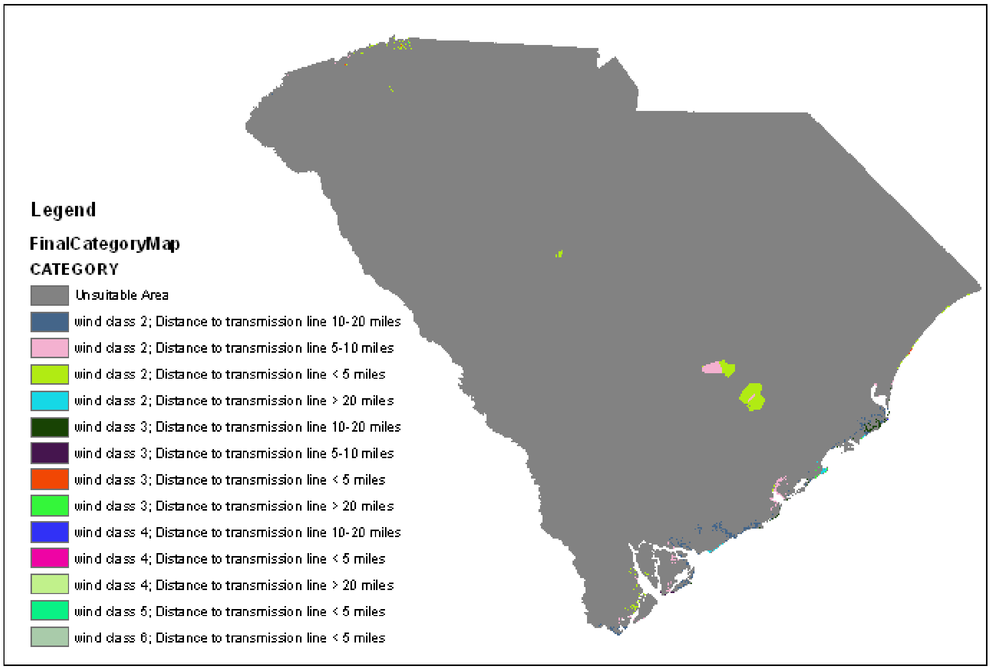
Figure 23.
Suitable Areas for Onshore Wind Power Generation



Specific Suitability Categories for Onshore Wind Power Generation

As follows, the suitable area for wind power generation was grouped into specific categories so that information compiled in this report would be in a format compatible with other wind power studies. As stated previously, wind power generation is directly related to wind speed, and theoretically, the power available at a given wind speed varies with the cube (the third power) of the average wind speed. Wind farm construction is also related to the distance to the utility line. A wind farm close to a utility line will incur less cost to connect to the power grid. To better understand the characteristics of the suitable onshore area for wind power generation, the suitable area was grouped into categories according to the wind speed and distance to utility lines. Figure 24 shows the geographic distribution of these categories.

Figure 24.
Onshore Wind Class Resources - Certain Distances to Major Transmission Lines



Area Calculation for Wind Resource Categories

To calculate the total on-shore wind power potential in South Carolina, it was necessary to calculate the area of the specific suitability categories. Table 8 shows the area for each category.

Table 8.
Total Area for Wind Power Categories
(Unit: km^2)

Distance to transmission line/ Wind power Classes	Wind Class 2	Wind Class 3	Wind Class 4	Wind Class 5
Distance to transmission line < 5 miles	292	5	1	0
Distance to transmission line 5-10 miles	143	3	1	0
Distance to transmission line 10-20 miles	159	39	1	0
Distance to transmission line > 20 miles	14	9	2	0
Total	608	56	5	0

Calculation of Wind Power Feasible Capacity and Feasible Generation

"Feasible capacity" refers again to the maximum potential that might reasonably be expected to be implemented. In the research, the feasible capacity was calculated using the following equation.

Feasible Capacity (MW) Calculation = Area (km^2)* Generation Potential Factor (MW/ km^2)

"Generation potential factor" refers to how much wind energy can be generated for each square kilometer. The analysis used in this article assumes that 5 MW/ km^2 of turbines are installed in areas determined to possess sufficient winds, and this is a standard assumption for wind power calculation. Table 9 shows the feasible capacity for wind resource categories.

Table 9.
South Carolina Total Feasible Capacity for Each Wind Resource Category

Feasible Capacity (MW)	Wind Class 2	Wind Class 3	Wind Class 4	Wind Class 5
Distance to transmission line < 5 miles	1460	25	5	0
Distance to transmission line 5-10 miles	715	15	5	0
Distance to transmission line 10-20 miles	795	195	5	0
Distance to transmission line > 20 miles	70	45	10	0
Total	3040	280	25	0

"Feasible generation" refers to the total feasible energy (GWh) that can be generated in one year. It was calculated using the equation:

Feasible Generation (GWh) = Feasible Capacity (MW) * Capacity Factor * 24*365/1000

"Capacity factor" is simply the wind turbine's actual energy output for the year divided by the energy output if the machine operated at its rated power output for the entire year. A reasonable capacity factor would be 0.25 to 0.30. A very good factor would be 0.40. The capacity factor is very sensitive to the average wind speed. Table 10 illustrates the value of capacity factors for each wind power class. Table 11 shows the feasible generation for specific wind resource categories. In summary, the total estimated feasible generation for South Carolina land-wind resources is 6005 GWh.

Table 10.
Capacity Factor for Different Wind Power Classes

Wind Class 2	Wind Class 3	Wind Class 4	Wind Class 5
20%	25%	30%	35%

Table 11.
Feasible Generation for Specific Wind Resource Categories
(Unit: GWh)

Feasible Generation (GWh)	Wind Class 2	Wind Class 3	Wind Class 4	Wind Class 5
Distance to transmission line < 5 miles	2557.92	54.75	13.14	0
Distance to transmission line 5-10 miles	1252.68	32.85	13.14	0
Distance to transmission line 10-20 miles	1392.84	427.05	13.14	0
Distance to transmission line > 20 miles	122.64	98.55	26.28	0
Total	5326.08	613.2	65.7	0

Summary

The feasibility analyses presented in this report uses Geographic Information System (GIS) techniques to investigate wind availability and accessibility for electric power generation in South Carolina. The maps shown in Figures 16 and 24 illustrate the geographic locations of offshore and land-based wind resources after geographic and infrastructure constraints were applied in the GIS analyses. The total estimated feasible generation for South Carolina offshore wind resources is 169,252 GWh; and the total estimated feasible generation for onshore wind power is 6005 GWh. This research represents a unique approach to the analysis of wind resources that can support South Carolina's efforts to develop a strategy for harvesting renewable energy.

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