A Geospatial Approach to Siting Wind Right in the Southeast

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Abstract

While installed wind turbine capacity continues to increase in the United States, a noticeable void exists in the Southeast due to a combination of poor wind resources, competing energy sources, and political opposition. As manufacturers develop turbines with a higher hub height to harness faster and smoother wind resources, many, including The Nature Conservancy, anticipate significant wind development in the Southeast. The identification of low environmental impact areas will not only lower the risk of project development but will also enable the identification of priority areas for transmission and distribution infrastructure. To capitalize on the opportunity to site wind right from the beginning, this study uses a GIS-based exclusion category approach to identify areas where installed wind power capacity is least likely to disrupt wildlife and sensitive habitats. The geospatial model creates maps where environmental and technical areas that are unsuitable for wind farms are removed. The model considers a sequence of five categories of land exclusion criteria. The resulting geospatial product suggests that even after removing sizable areas from consideration, there is significant land for wind development to meet the energy and climate needs of the Southeast region.

Keywords: GIS, wind energy, Southeast region
Executive Summary

Utility-scale wind farms are a source of clean, low-cost electricity and a critical component of a strategy to decarbonize the energy sector. However, while wind farms do not emit pollutants or require a large volume of water or fuel to operate, their development is concerning to conservation groups due to their footprint and potential impact on the environment.

In this study we use The Nature Conservancy’s Resilient and Connected Landscapes dataset to map out areas that could be devoted to wind power development without impacting climate corridors, areas of high biodiversity and resilience.

The first section of this report shows that wind resources in the Southeast are underdeveloped compared to the greater landscape of wind development in the US. As turbine hub heights increase and costs continue to decrease, wind development in areas of traditionally poor wind resource will be unlocked. An overview of different types of environmental impacts due to wind turbines is also provided.

The second section examines past geospatial approaches to site wind turbines, including The Nature Conservancy’s previous mapping exercises Site Wind Right and the Power of Place, which covered the US’s west, southwest and midwest. The voluntary US Fish and Wildlife Service Land-Based Wind Energy Guidelines is an influential framework for minimizing environmental impacts of wind development and is also summarized here.

The third section provides a list and rationale for the chosen exclusion categories which are the geospatial constrains that make it either impossible or undesirable to build wind projects. The methodology using ESRI’s geospatial software ArcGIS and the buffer distances is also described.

The fourth section contains the maps of exclusion categories and the resulting outputs. Calculations to convert low impact wind development areas into wind capacity and generation values are also explained here to show that a minimum of 356 GW can be installed.

The last section offers some policy suggestions and possible future data additions.

This report makes several key points and recommendations:

- Wind resources in the Southeast are currently underutilized. According to our dataset, even with environmental constrains, there is enough land for at least 356 GW of wind capacity in the Southeast.
- Transmission infrastructure coexists with much of the areas of low impact wind development; further analysis on available capacity on these transmission lines is needed.
Abbreviations and Acronyms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABC</td>
<td>American Bird Conservancy</td>
</tr>
<tr>
<td>BLM</td>
<td>Bureau of Land Management</td>
</tr>
<tr>
<td>DOE</td>
<td>US Department of Energy</td>
</tr>
<tr>
<td>EERE</td>
<td>Office of Energy Efficiency and Renewable Energy</td>
</tr>
<tr>
<td>eGRID</td>
<td>Emissions &amp; Generation Resource Integrated Database</td>
</tr>
<tr>
<td>EIA</td>
<td>Energy Information Administration</td>
</tr>
<tr>
<td>FAA</td>
<td>Federal Aviation Administration</td>
</tr>
<tr>
<td>FEMA</td>
<td>Federal Emergency Management Agency</td>
</tr>
<tr>
<td>HIFLD</td>
<td>Homeland Infrastructure Foundation-Level Data</td>
</tr>
<tr>
<td>NREL</td>
<td>National Renewable Energy Laboratory</td>
</tr>
<tr>
<td>PADUS</td>
<td>Protected Areas Database of the United States</td>
</tr>
<tr>
<td>POP</td>
<td>Power of Place</td>
</tr>
<tr>
<td>SWR</td>
<td>Site Wind Right</td>
</tr>
<tr>
<td>TNC</td>
<td>The Nature Conservancy</td>
</tr>
<tr>
<td>UNFCCC</td>
<td>United Nations Framework Convention on Climate Change</td>
</tr>
<tr>
<td>USACE</td>
<td>United States Army Corps of Engineers</td>
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<tr>
<td>USGS</td>
<td>United States Geological Survey</td>
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</table>
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Introduction
Climate Goals and Role of Wind Energy in US Energy

The Biden Administration’s goal of carbon neutrality has motivated the release of the Clean Energy Revolution and Environmental Justice programs and the US returned to the Paris Agreement with strong support for the development of clean energy (FACT SHEET, 2021). Wind farms are important because they enable the US to contribute to UNFCCC’s commitment of “stabilizing greenhouse gas concentrations in the atmosphere at a level that will prevent dangerous human interference with the climate system, in a time frame which allows ecosystems to adapt naturally and enables sustainable development” (Congressional Research Service), and to meet the Paris Agreement’s goal of achieving a global warming of no more than 2 degrees Celsius (UNFCCC). However, assuming that current laws and regulations are unchanged, EIA projects that total U.S. energy-related CO₂ emissions will be about 4,807 million metric tons in 2050, which is about 5% more than the amount in 2020 (2018). Only by adopting a tougher clean energy policy can the energy industry work together to achieve Paris Agreement’s goal.

The Wind Powers America Annual Report of 2019 released by the American Wind Energy Association (AWEA) shows wind energy was the largest source of renewable power, supplying 7.2% of the country’s electricity. Installed wind capacity in excess of 100 GW avoids 198 million metric tons of CO₂ emissions and the consumption of 103 billion gallons of water annually. This capacity is expected to increase because wind energy is cost competitive with other sources and its installation costs are expected to continue to decline in the next three decades (International Renewable Energy Agency, 2019).

Wind energy development creates substantial economic benefits creating thousands of jobs along its supply chain, providing new sources of income for farmers in the form of land lease payments, and increases the local tax base (Lantz & Tegen, 2009). Moreover, being an abundant and inexhaustible domestic energy source, wind reduces the US energy security risk. Although all these benefits come hand in hand with significant challenges for its integration into the electric power system, given its non-controllable variability and partial unpredictability (Pérez-Arriaga & Batlle 2012), the growth of wind capacity will continue through the implementation of operational and technical strategies such as improved forecasting, larger
balancing authority areas, shorter dispatch windows, and incorporating demand response and more flexible generation sources onto the grid (Bird et al., 2013).

Pushing this growth are the national and state goals for developing both onshore and offshore wind resources. The Biden Administration has set a national target to install at least 30 GW of operating offshore wind capacity by 2030 (The White House, 2021). Many states also have separate goals for wind energy, for example, the goal of Maine is to achieve 8,000 MW of installed wind capacity by 2030, including 5,000 MW from offshore and coastal. The goal of New York is to implement 2,400 MW of offshore wind by 2030 (State Renewable Portfolio Standards and Goals, n.d.). A report from DOE shows some incentives are implemented for wind project developers and investors, such as tax credits and financing mechanisms (2018).

Status of the Wind Industry in the Southeast
Although wind energy has continuously increased its participation in US electric power generation, recent obstacles have limited wind development in the Southeast. According to IEA Renewable analysis (2020), annual net wind capacity additions in the United States were expected to reach 65 GW in 2020, 8% more than in 2019, but the data from the National Renewable Energy Laboratory shows very little wind power generation capacity in the Southeast region due to political preference for fossil fuels. In 2017, North Carolina State Senate majority leader Harry Brow pushed through an 18-month moratorium on wind energy projects reasoning that wind farms could threaten the future of the region's military bases in the state (Ross, 2019). In support of wind farm development, Katharine Kollins, president of the Southeastern Wind Coalition, reported in 2019 that during the two years of operations, wind farms have never posed a threat to the training and mission of local military bases (Coastal Review Online). The moratorium ended on Dec. 31, 2018 (Ross, 2019). Compared to wind energy development, the Southeast region has tremendous solar potential and supportive public policies for its exploitation. The EPA’s eGRID data set showed that in 2018, the total nameplate capacity of solar energy in the Southeast states was 16822.3 MW. The Southern Alliance for Clean Energy projects that solar energy capacity in the Southeast region will reach 17,000 MW by 2021 (Jacob, 2020). The resource will continue to compete with natural gas, for which in the Southeast there is a power generation capacity of 211472.1 MW. In fact, Louisiana and Florida were in the top 10 natural gas energy consuming states in 2018 (Sönnichsen, 2021).
Developing wind farms is still a challenge in the Southeast because of low wind speeds (EIA). In general, wind turbines height should be located in areas with an annual average wind resource greater than 7.0 m/s. According to the NREL average wind speed at 80 m map the US wind belt has speeds in the range from 4 m/s to 10 m/s, while in the Southeast ranges from 4 m/s to 6 m/s. Paul Veers, chief engineer at the National Wind Technology Center, summarizes this reality saying “the main difference between the Southeastern US and the rest of the country is the intensity of the wind resource” (Irfan & Zarracina, 2019). Furthermore, data from eGRID reveals that only North Carolina, Tennessee, Virginia, and West Virginia have constructed wind farms to a meager total nameplate capacity of 1,079.3 MW.

**Figure 1 Annual Average Wind Speed at 80 m in the U.S.**

Despite not having a rich wind resource, the U.S. DOE (2015) projects significant growth in the Southeast’s wind generating capacity for 2050. This is because taller turbines, which are increasingly being deployed, can reach into higher wind speeds (Rinne et al., 2018). Also, even though wind speeds in the Southeast are low compared to other regions, the places with abundant wind resources are still underdeveloped, including the coastal areas which represent vital opportunities for energy and economic development in rural counties in Louisiana, the Carolinas.
Environmental Impact of Wind Farms

While wind turbines themselves do not create air pollution and are able to offset the energy used in their manufacturing, transportation, and construction within a few months of operation, significant environmental impacts remain to wildlife and nearby inhabitants. Additionally, the generator inside the wind turbine that converts rotational kinetic energy into electrical energy also creates a magnetic field and thus can interfere with radar and telecommunication facilities. Health concerns are often cited by the public as reasons for wind opposition. The Canadian Family Physician journal also states that human health can be harmed by industrial wind turbines if they are sited too close to residents, but harm can be avoided if there are adequate protections enacted through wind siting guidelines (Jeffery et al., 2013). However, McCallum et al. states that the electromagnetic field caused by wind turbines at the base are low and insignificant at distance of 500 m (2014). A summary of wind turbine impacts as summarized by Saidur et al (2011). is included:

Table 1 Negative environmental impacts of wind turbines

<table>
<thead>
<tr>
<th>Birds</th>
<th>Turbine collision mortality rate is estimated to average 3.1 birds/MW/yr with a range of 0.9 to 11.7 birds/MW/yr. Lighting conditions, weather, tower design, and height of flight can all impact avian mortality rates.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bats</td>
<td>Similar to birds, the threat wind turbines pose on bats is estimated to average 4.6 bats/MW/yr with a range of 0.9 to 43.2 bats/MW/yr</td>
</tr>
<tr>
<td>Raptors</td>
<td>Raptor mortality rates are significantly lower than that of birds and bats.</td>
</tr>
<tr>
<td>Noise</td>
<td>Due to moving parts inside turbine (i.e. gearbox, generator, bearings) and aerodynamics due to movement of air over blades creating a “whooshing” sound.</td>
</tr>
<tr>
<td>Visual Impact</td>
<td>Due to negative reactions and varies with personal preference. Can be mitigated by considering turbine color choice and decreasing contrast with surrounding. Shadow flickering of wind turbines can also occur when blades reflect sunlight or causes rhythmic shadows.</td>
</tr>
</tbody>
</table>

Many of these environmental impacts can be mitigated by either altering the design and engineering of wind turbines or by siting wind turbines to mitigate these environmental impacts.
Other than bird and bat collisions, habitat loss, habitat degradation, and habitat fragmentation can also occur due to the construction of wind farms at unsuitable locations and thus require the consideration of landscape scale data.

**Objective**

This project will determine land availability for the responsible siting of wind farms based on the most recent data on ecological, regulatory, technical, and socioeconomic considerations in the Southeast including, the states of Louisiana, Mississippi, Alabama, Florida, Georgia, South Carolina, North Carolina, and Tennessee. The project’s client, The Nature Conservancy (TNC), is supportive of the “rapid expansion of renewable energy while protecting wildlife and natural habitats” (TNC, 2019). The environmentally responsible siting of solar projects has been explored in prior analyzes such as Oberholzer and Shuster’s MP (Shuster and Oberholzer) as well as TNC’s Principles of Low Impact Solar Siting and Design (Kalies and Hartung, 2019), but wind spatial guidelines still need to be explored for the Southeast. This project applies to the Southeast the approach laid out in TNC’s Site Wind Right (SWR) and Power of Place (PoP) studies which have provided similar spatial guidelines for wind development in the Midwest and the West. This study followed four steps: (1) literature review, (2) determination of categories of exclusion criteria, (3) data collection, (4) GIS analysis and map visualization, and (5) results description.

**Literature Review**

**USFWS Land-Based Wind Energy Guidelines**

The US Fish and Wildlife land-based Wind Energy Guidelines provides instructions for a structured voluntary process that reduces environmental impacts in all stages of a wind farm project from siting to decommissioning. The guidelines emphasize early and comprehensive engagement of all stakeholders including various levels of government, tribes, and conservation agencies. The multi-tiered approach can be separated into five stages including: site evaluation, site characterization, field studies, post-construction studies, and other post-construction research. Each tier provides resources to questions that the developer should seek to address through existing field studies, research methodologies, and potential mitigation strategies. A decision point exists for each tier after the necessary requirements and data are collected; the iterative approach is designed to reduce development risk by providing numerous exit ramps.
The increase in data requirements also scales to correspond to each development stage to ensure resources are spent efficiently. Since this is a voluntary guideline, wind developers must complete due diligence and ensure that the right permitting authorities are identified at the local, state, and federal level, while also engaging the public to ensure development delays are minimized.

Previous Approaches to Siting Wind

This analysis builds upon two approaches that TNC has previously undertaken to siting wind in the US including PoP and SWR. The PoP study covers western United States including Washington, Oregon, California, Nevada, Arizona, New Mexico, Colorado, Utah, Wyoming, Idaho, and Montana. For the geospatial component of the analysis, the environmental exclusion categories and land constraints on solar and wind were arranged from 1 to 4 decreasing in stringency in terms of legal and regulatory requirements; the four respective categories are legally protected, administratively protected, high conservation value, and landscape intactness. Similarly, the SWR project covers 17 states in the US wind belt and heavily emphasizes wind development that reduces wildlife impacts and identifies areas where wind development is unlikely to encounter significant wildlife-related conflicts (Site Wind Right, 2019). Since this region is home to many endangered species, the geospatial analysis was able to map out species-specific data layers such as migratory birds, bats, eagles, and prairie/sage grouse, whooping crane stopover sites, big game habitats, eagle and other raptor nesting areas, and other threatened and endangered species. The end result of both studies provided clear spatial guidelines for wind development and estimated the total installed wind capacity potential.

Other studies by Miller & Li (2014), Baban & Parry (2001), and Rodman & Meentemeyer (2006) have also used multi criteria analysis to select the best wind siting areas using mainly technical and infrastructure considerations such as distance to transmission lines, population density, and roads. Similar to SWR, a binary approach to finding the least impact wind siting areas was used instead of assigning different weights depending on distance. However, not all of the SWR methodology from Central US can be transferred to the Southeast region since there are fewer endangered and protected species; thus, the use of TNC’s Connected and Resilient Landscapes for Terrestrial Conservation dataset (2016) will serve as a proxy to represent areas that contain connected micro-climates, and areas or corridors of highly concentrated plant and animal movement responding to climate change.
Methodology
Determination of Exclusion Categories

Based on the PoP study and in consultation with Liz Kalies, the exclusion categories were separated into five total categories. Categories 1 through 4 decrease in stringency of formal environmental protection and conservation, while Category 5 includes non-environmental limitations to wind development. The goal of criteria selection is to identify the relevant setbacks to regulate the placement and spacing of structures on properties (Lang & Jenkins, n.d.) and can be highly variable depending on locality. In the Southeast, wind facility siting is under the purview of local authority or a hybrid authority, while only North Carolina is under state-level regulation (Kahn & Shields, 2020). The following tables describe the datasets used for the geospatial analysis and present the reasoning for any processing if required based on setback distances.

Category 1 encompasses areas under legal protection and consists of the PADUS and NC’s Protected Ridge Act. The PADUS is a comprehensive inventory of areas that are protected from disturbance and conversion from its natural state from a variety of sources including federal, state, regional, local, NGO, private, and partnership areas. The database is not specific to energy siting but also was also curated for potential uses affecting economic development of
places, outdoor recreation, and the Endangered Species Act. All areas in the PADUS inventory were included for category 1 and include areas such as Wild & Scenic Rivers, National Forests and Parks, conservation space of private and public lands. Noticeable areas include the southern peninsula in Florida covering the Everglades National Park, Big Cypress National Preserve and Francis S. Taylor Wildlife Management Area. Other areas such as the Great Smoky Mountains National Park in Tennessee, Eglin Air Force Base in Florida and the Okefenokee National Wildlife Refuge in Georgia can be observed.

The North Carolina Mountain Ridge Protection Act of 1983 forbids the construction of tall buildings or structures on protected mountain ridges. In other Southeast States, there are no specific protected ridge laws, so protected ridge areas were only eliminated in North Carolina. According to N.C.G.S. § 113A-206 (1983), a protected mountain ridge is defined as “mountain ridges whose elevation is 3000 ft and whose elevation is 500 or more feet above the elevation of an adjacent valley floor”. To translate the law into geospatial language, we used a neighborhood window of 1000 ft to determine the minimum elevation that would correspond to the adjacent valley floor in reality.

Table 2 Category 1

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Reasoning</th>
<th>Exclusion Criteria</th>
<th>Data Type</th>
<th>Resolution</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>PADUS</td>
<td>Contains areas that are either parks or protected lands</td>
<td>N/A</td>
<td>Polygon</td>
<td>N/A</td>
<td>USGS</td>
</tr>
<tr>
<td>North Carolina</td>
<td>Ridges protected by The North Carolina Mountain Ridge</td>
<td>Relevant cells</td>
<td>Raster</td>
<td>30 m</td>
<td>User generated</td>
</tr>
<tr>
<td>Protected Ridge</td>
<td>Protection Act of 1983</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Category 2 represents area that is administratively protected. While these areas do not indicate a firm exclusion of wind development, land use reviews and other procedures need to be observed to fulfill criteria to build on US Army Corp of Engineers areas and tribal areas, so all criteria in this category are eliminated from the study area. Wetlands and flood zones are also included in this category due to their administrative protection status.

Table 3 Category 2

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Reasoning</th>
<th>Exclusion Criteria</th>
<th>Data Type</th>
<th>Data Resolution</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Category 3 represents areas of high conservation value while Category 4 represents landscape intactness. Both categories utilize TNC’s Connected and Resilient Landscape dataset but are different in that Category 4 contains climate corridors while Category 3 contains resilient areas and climate flow zones. An effort of 60 scientists and 70 source datasets, The Connected and Resilient Landscape methodology maps out areas of above average resilient scores, areas of concentrated, diffuse, or riparian climate flow areas, and areas of either confirmed rare species or high taxa diversity. This dataset is different from traditional datasets in that it not only represents current areas of high biodiversity, but also characterizes areas that are highly sensitive to the changes that climate can cause to wildlife and plant biodiversity. Species-specific datasets such as ABC’s Wind Risk Assessment Map that characterize areas of high importance to birds were not included. There is overlap between the TNC’s Resilient and Connected dataset and the ABC bird area, with 32% of the land in the TNC’s Resilient and Connected dataset overlapping with 67% of the land in the ABC bird map. The ABC map is attached in the appendix.
Table 4 Category 3 and 4

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Reasoning</th>
<th>Selection Criteria</th>
<th>Data Type</th>
<th>Data Resolution</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>TNC Resilient and Connected Landscape</td>
<td>As climate changes, plants and animals will need to relocate to survive. Climate-resilient sites, confirmed biodiversity locations, and species movement areas (zones and corridors) are taken into consideration.</td>
<td>Resilient area, climate flow zone and climate corridor (all except vulnerable)</td>
<td>Raster</td>
<td>30 m</td>
<td>TNC</td>
</tr>
</tbody>
</table>

Category 5 considers non-environmental conditions in the form of economic and technical constraints that further limit the suitability of an area for wind development. NREL’s annual average wind speed is combined with a relative elevation model and slope model to map out the technically feasible wind area. While the hub height of The Amazon Wind Farm North Carolina – Desert Wind in eastern North Carolina is at 92 m, a wind speed of 6.5 m/s was chosen as the cutoff at a hub height of 120 m with the assumption that costs for taller turbines would decrease. Since the NREL wind data is a computer model output based on meteorological data from 2007 to 2013, the granularity of site-specific wind speeds was improved upon by using a relative elevation model. Using the digital elevation model as the input, the relative elevation model uses the raster calculator to calculate if the cell is higher than its surrounding which implies access to higher quality wind resources due to less mixing and friction. According to White et al. (2014), the equation to calculate the relative elevation is as follows:

\[ f(x) = x - \frac{(a+b+c+d)}{4} \]

where \( x \) is the input cell, \( a, b, c, \) and \( d \), are mean elevation of cells in annulus of internal radius of 3 km, 6 km, 12, km, and 24 kms respectively. The outer radius is internal radius + 0.06 km for all. The mean value of the relative elevation model was 20.88 m and all values below the mean were removed. Areas with pronounced slopes which make it difficult or prohibitively expensive to construct wind farms and areas where siting is not possible due to existing infrastructure such as urban areas, railway, airports, radar stations, and existing wind farms are also included.
### Table 5: Wind Development Technical Criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Reasoning</th>
<th>Selection Criteria</th>
<th>Data Type</th>
<th>Data Resolution</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind speed</td>
<td>“Areas with annual average wind speeds around 6.5 meters per second and greater at an 80-m height are generally considered to have a wind resource suitable for wind development” (Office of Energy Efficiency &amp; Renewable Energy)</td>
<td>&gt; 6.5 m/s</td>
<td>Raster</td>
<td>2000 m</td>
<td>NREL</td>
</tr>
<tr>
<td>Slope</td>
<td>According to X, Y, Z, the range of acceptable slopes is between 10 and 84% Baban &amp; Parry, 200; Rodman &amp; Meentemeyer, 2006; NREL, 2008)</td>
<td>&lt; 84%</td>
<td>Raster</td>
<td>30 m</td>
<td>USGS</td>
</tr>
<tr>
<td>Relative Elevation</td>
<td>“Areas that are higher in elevation relative to their immediate surroundings, and thus have greater wind exposure” (White et al, 2014)</td>
<td>&gt; Mean Relative Elevation Value</td>
<td>Raster</td>
<td>30 m</td>
<td>USGS</td>
</tr>
<tr>
<td>Urban Area</td>
<td>Urban wind energy has not been widely adopted (Kammen &amp; Sunter, 2016). For information about noise and health impacts that require a setback from homes of at least 2 kilometers (European Setbacks (minimum distance between wind turbines and habitations), 2009).</td>
<td>&gt;2 km</td>
<td>Polygon</td>
<td>N/A</td>
<td>US Census Bureau</td>
</tr>
<tr>
<td>Railway</td>
<td>In no case less than 500 feet (Oteri, 2018).</td>
<td>&gt;500 feet</td>
<td>Polyline</td>
<td>N/A</td>
<td>HIFLD</td>
</tr>
<tr>
<td>Airport</td>
<td>Wind turbine wakes pose a significant roll hazard to general aviation aircraft at downwind distances as far as 4.57 km (2.84 miles) (Tomaszewski et al., 2018)</td>
<td>&gt;5 km</td>
<td>Point</td>
<td>N/A</td>
<td>FAA</td>
</tr>
<tr>
<td>Radar Stations</td>
<td>Turbines sited at least 18 km from the radar generally only impact the lowest radar scan at 0.5 degrees elevation, and clutter is confined to the wind farm area (NOAA).</td>
<td>&gt;18 km</td>
<td>Point</td>
<td>N/A</td>
<td>HIFLD</td>
</tr>
<tr>
<td>Existing Wind Farms</td>
<td>Rule of thumb is to install a wind turbine 150 meters (492.1 feet) away from any nearby obstruction (Gaughan, 2019). Areas within 1.6 km of existing wind turbines are considered unsuitable for new wind development (Site Wind Right, 2019).</td>
<td>&gt;150 m</td>
<td>Points/Polygon</td>
<td>N/A</td>
<td>USGS</td>
</tr>
</tbody>
</table>

### GIS Approach

All the necessary geospatial data on land and technical constraints were obtained from publicly available federal, state, or NGO websites. A full list of the data sources is available [here](#). Arcpy, a python based geospatial scripting package, was used to preprocess the various input datasets, while Model Builder, a visual programming interface as part of ArcGIS Pro, was used to analyze viable wind development areas. Both processes provide ease of adjustment in certain
variables such as buffer distances and provides an easy way to document and reproduce the workflow. Python script and ModelBuilder can be accessed here.

A high-level overview of the 5 steps follows for the geospatial analysis is provided in Figure 2. The first step consists of downloading the databases. Since most of the data relevant to this study are available at a national level, data are first processed so that only values in the study area are kept. The data layer is then processed depending on the selection criteria. For example, wind farms must be located 5 km away from airports, so the buffer tool is used to identify a circle from the point location of the airport. Other than the buffer tool, the select-by-attribute tool was also used to cutoff values less than or greater than the selection criteria.

The raster-to-polygon tool is used to prepare for step 5 (elimination) to allow for the use of the erase tool since input features can only be feature classes. The individual criterions are combined using the merge tool and then the dissolve tool is used to aggregate the separate polygons. To account for artifacts that may result from geospatial analysis, any area less than 20 km\(^2\) or 4942 acres was eliminated from the final output after Category 5. The minimum area value is based on SWR’s methodology and is important to note that this value is larger than the minimum area required for one wind turbine which is estimated to be 1.5 acres based on the minimum distance required between turbines.

![Diagram showing five steps followed for geospatial analysis](image_url)

*Figure 3 Five steps followed for geospatial analysis*
Cell Size Resolution

The two main types of geospatial data that ArcGIS can read and manipulate are vectors and raster. To represent areas, vectors use a combination of lines and nodes to form shapes while raster data uses cells of equal length to represent features. Common uses of vector data are point sources and roads, while raster data is used to represent land cover and elevation. The granularity of our geospatial analysis was limited by the resolution of available datasets. The final map output is provided in raster format at 30 m resolution. To account for the fact that NREL wind speed data was provided at 2 km resolution, the relative elevation model at 30 meters was used as the input while the wind speed layer was used as a mask so that the output of wind speed would still be at 30 m resolution. An example of resolution mismatch is shown below as the blue represents a higher resolution while the gray represents a lower resolution dataset.

![Resolution Mismatch Illustration](image)

*Figure 4. Illustration of the mismatch in the resolution of the wind speed dataset (grey) and the Resilient & Connected dataset (blue)*

Results

Maps

The aggregated outputs from each category from 1 to 4 that represent areas unsuitable for wind development are shown below in Figure 3.
Figure 5 Environmental Exclusion Category 1. Shaded areas are unsuitable for wind power development
Figure 6 Environmental Exclusion Category 2, sequentially overlaid. Shaded areas are unsuitable for wind power development.
Figure 7: Environmental Exclusion Category 3, sequentially overlaid. Shaded areas are unsuitable for wind power development.
Figure 8 Environmental Exclusion Category 4, sequentially overlaid. Shaded areas are unsuitable for wind power development.
As shown in the maps, 140 million acres, representing 47% of the Southeast area, remain after excluding areas in the first four categories. The considerations of category 5 results in the exclusion of 109 million acres so only 31 million acres remain as suitable for economic and environmentally responsible wind power development.
Figure 10 Area suitable for wind power development in 267 million acres and as 89% of the total considered in the Southeast, after the one environmental exclusion criteria is considered.
Figure 11 Area suitable for wind power development in 191 million acres and as 64% of the total considered in the Southeast, after the two environmental exclusion criteria are considered.
Figure 12 Area suitable for wind power development in 145 million acres and as 48% of the total considered in the Southeast, after the three environmental exclusion criteria are considered.
Figure 13 Area suitable for wind power development in 140 million acres and as 47% of the total considered in the Southeast, after the four environmental exclusion criteria are considered.
Figure 14 Area suitable for wind power development in 31 million acres and as 10% of the total considered in the Southeast, after the non-environmental exclusion is considered.
Figure 15 Area suitable for wind power development in 24 million acres and as 8% of the total considered in the Southeast, after eliminating minimum area criteria is considered
Calculation of Wind Farm Capacity and Generation Potential

In this section of the paper, we make several assumptions to translate our estimates of low impact wind development areas into meaningful metrics of energy resource. To estimate wind generation capacity, NREL, suggests that utility scale wind turbines of 1-10 MW require 44.7 acres per MW with a standard deviation of 25 acres/MW. The results in GW of available area by state are shown below in Table 1. It is not surprising that Florida ranks at bottom of the table due to low wind speeds even at 120 m hub height.

<table>
<thead>
<tr>
<th>State Name</th>
<th>Area (Million Acre)</th>
<th>Capacity (GW)</th>
<th>Lower Bound (GW)</th>
<th>Upper Bound (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Carolina</td>
<td>4.48</td>
<td>101.9</td>
<td>65.0</td>
<td>235.9</td>
</tr>
<tr>
<td>Kentucky</td>
<td>3.72</td>
<td>84.5</td>
<td>53.9</td>
<td>195.7</td>
</tr>
</tbody>
</table>

Table 6: Estimated area suitable for wind development and corresponding capacity (in GW) assuming the average (44 acres/MW) and low (29 acres/MW) and upper bounds (69 acres/MW) of land area requirements per MW of installed capacity
Table 1 shows that the 24 million acres suitable for wind development in the Southeast could accommodate between 356 and 1300 GW of wind power generation capacity. Estimating the wind generation potential for this level of potential wind capacity requires an assumption about the capacity factor of wind farms. The annual capacity factor of a wind farm is equal to its yearly power generation (in MWh) divided by the production that would have been observed if the farm had generated electricity at its full capacity during the 8760 hours of the year. While estimates of annual electricity generation and capacity factor must consider location-specific wind speeds, it is possible to look at historical production data from farms in the region. We observed the reported capacity factor for existing wind farms in the Southeast region. According to the EPA’s eGRID database, the capacity factor of these wind facilities in 2018 ranged between 15% and 24%, with the average being 20%. Only three southeastern states, North Carolina, Tennessee, and Virginia, had existing wind farms in 2018. For comparison, the average wind capacity factor for the entire U.S. during the same year, according to the same database, was 30%. Tables 2 to 4 below show a range of annual net generation in GWh using the range of possible capacity factors for each of three possible levels of wind power capacity that could be installed in the Southeast.

<table>
<thead>
<tr>
<th>State</th>
<th>Wind Generation</th>
<th>Solar Generation</th>
<th>Biomass Generation</th>
<th>Total Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Louisiana</td>
<td>2.93</td>
<td>66.6</td>
<td>42.5</td>
<td>154.3</td>
</tr>
<tr>
<td>Mississippi</td>
<td>2.76</td>
<td>62.7</td>
<td>40.0</td>
<td>145.3</td>
</tr>
<tr>
<td>Tennessee</td>
<td>3.14</td>
<td>71.4</td>
<td>45.6</td>
<td>165.4</td>
</tr>
<tr>
<td>Virginia</td>
<td>2.72</td>
<td>61.7</td>
<td>39.4</td>
<td>143.0</td>
</tr>
<tr>
<td>Georgia</td>
<td>2.23</td>
<td>50.8</td>
<td>32.4</td>
<td>117.6</td>
</tr>
<tr>
<td>South Carolina</td>
<td>1.46</td>
<td>33.3</td>
<td>21.2</td>
<td>77.1</td>
</tr>
<tr>
<td>Alabama</td>
<td>1.08</td>
<td>24.4</td>
<td>15.6</td>
<td>56.6</td>
</tr>
<tr>
<td>Florida</td>
<td>0.02</td>
<td>0.4</td>
<td>0.2</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>24.54</strong></td>
<td><strong>557.7</strong></td>
<td><strong>355.7</strong></td>
<td><strong>1291.6</strong></td>
</tr>
</tbody>
</table>
Table 7. Wind farms’ power generation capacity for the southeastern U.S. and estimated production assuming 558 GW of installed power capacity and 3 levels of annual capacity factor: 20% (average), 15% (lower bound), 24% (upper bound).

<table>
<thead>
<tr>
<th>Average Capacity Across 10 States (GW)</th>
<th>Annual net electricity generation (GWh)</th>
<th>Upper Bound (GWh)</th>
<th>Lower Bound (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southeast Region</td>
<td>557.7</td>
<td>977,172</td>
<td>1,172,606</td>
</tr>
</tbody>
</table>

Table 3. Wind farms’ power generation capacity for the southeastern U.S. and estimated production assuming 356 GW of installed power capacity and 3 levels of annual capacity factor: 20% (average), 15% (lower bound), 24% (upper bound).

<table>
<thead>
<tr>
<th>Average Capacity Across 10 States (GW)</th>
<th>Annual net electricity generation (GWh)</th>
<th>Upper Bound (GWh)</th>
<th>Lower Bound (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southeast Region</td>
<td>355.7</td>
<td>623,124</td>
<td>747,749</td>
</tr>
</tbody>
</table>

Table 4. Wind farms’ power generation capacity for the southeastern U.S. and estimated production assuming 1300 GW of installed power capacity and 3 levels of annual capacity factor: 20% (average), 15% (lower bound), 24% (upper bound).

<table>
<thead>
<tr>
<th>Average Capacity Across 10 States (GW)</th>
<th>Annual net electricity generation (GWh)</th>
<th>Upper Bound (GWh)</th>
<th>Lower Bound (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southeast Region</td>
<td>1291.6</td>
<td>2,262,925</td>
<td>2,715,509</td>
</tr>
</tbody>
</table>

Table 5. Summary of Wind farms’ power generation capacity for the Southeastern U.S.

<table>
<thead>
<tr>
<th>Annual net electricity generation (GWh)</th>
<th>Upper Bound (GWh)</th>
<th>Lower Bound (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southeast Region</td>
<td>977,172</td>
<td>2,715,509</td>
</tr>
</tbody>
</table>

As shown, under different assumptions of land requirements for wind power development and capacity factor, annual generation production would range between 470 TWh and 2715 TWh. If only 980 TWh were generated, this would equal the total electric power generated in the Southeast in 2018, twice as much as total natural gas generation, and 1700 times more than current wind power generation.
Table 6. Illustration of wind power generation potential if 1 million GWh of power generation capacity are developed.

<table>
<thead>
<tr>
<th></th>
<th>Existing Plant annual net generation in 2018* (GWh)</th>
<th>Ratio of 1,116 TWh (low-mid range estimate) potential wind power generation to generation from different sources in 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>580</td>
<td>1700</td>
</tr>
<tr>
<td>Gas</td>
<td>487,400</td>
<td>2</td>
</tr>
<tr>
<td>All energy</td>
<td>1,169,630</td>
<td>0.8</td>
</tr>
</tbody>
</table>

*Annual generation reported by eGRID2018

Conclusion

This analysis combines five environmental and technical considerations that must be considered to site wind right in the Southeast. However, existing local zoning ordinances are omitted from the analysis and therefore the areas available for wind development may be smaller than the estimates we provide. Furthermore, offshore wind capacity was completely omitted from this analysis; according to NREL, an estimated 144 GW of unsubsidized offshore wind is economically possible by 2027. Considering offshore wind potential in future studies is important as it gains traction and would require an understanding of offshore wind technology cost trajectories, BOEM’s current offshore wind lease siting process, and data on current marine conservation areas.

Taking inspiration from Texas’ Competitive Renewable Energy Zone (CREZ), this dataset can be used to identify and designate areas that are favorable for wind development that would reduce development risk, streamline the interconnection process and reduce the need power system modelling. The CREZ in Texas works by identifying areas of rich wind resource areas then building source agnostic transmission lines to connect to population centers. Working with state legislators, similar initiates could be set up in the Southeast to encourage renewable energy development. Since there are so few wind turbines currently in the Southeast, newly constructed projects should be compared to this dataset to validate and monitor if this study has made a material impact on the wind development process.

While our process and dataset included the most significant exclusion criteria, other datasets could also be included in future iterations of the map to consider mines, population density, distance to access roads, and inclusion of other land cover datasets. Existing structures
like mines, landfills, and industrial sites in rural areas are not captured in any of the datasets included but these areas would obstruct the construction of wind farms. While urban areas are mapped out according to census data, another approach to quantify the impact of visual and sound disturbances to the non-urban population could be to use population density data by census block; a threshold would need to be decided as a cutoff point. Distance to access roads would lower construction costs as construction material and turbine equipment would be easier to transport from factory to site. A remote sensing-based land cover dataset such as USGS’s National Land Cover Database could also be used to better understand wind resource quality as different surfaces represent different friction coefficients that could lower wind speeds or introduce more turbulence.

The final determination of land availability for wind development will ultimately be a consequence of local ordinances that developers would also need to comply with before constructing a wind farm, such as access standards and easements, aesthetics of turbines, electrical and equipment standards, and permitting processes (Oteri, 2008). Our dataset is by no means comprehensive and not meant to be applied at the parcel or site level.

Using NREL’s land use by technology type values of between 19 and 69 acres/MW, a rough estimate of the onshore wind power capacity that could be installed in the Southeast ranges between 356 and 1300 GW. Assuming a capacity factor of between 15% and 24% for wind farms in the region, this capacity could generate between 470TWh and 2715TWh. While the range is wide, it is worth noting that the low bound of this estimate would replace all the electricity generation obtained from natural gas in 2018 and half the electricity obtained from all sources in the region. Of course, the wind capacity that may be economically developed may be further reduced after considering constraints on power transmission capacity, interconnection availability, land leasing opportunities, and stakeholder values.


Figure 17 Relative elevation map, and the areas in red are higher than its surroundings. Riverbeds and valleys can be traced out as non-red areas.
Figure 18 Unsuitable areas for wind power development identified by considering the category 1
Figure 19 Unsuitable areas for wind power development identified by considering the category 2
Figure 20 Unsuitable areas for wind power development identified by considering the category 3
Figure 21 Unsuitable areas for wind power development identified by considering the category 4
Figure 22 Unsuitable areas for wind power development identified by considering the category 5
Figure 23 Comparison of TNC’s RNC dataset vs. ABC’s Wind Risk Assessment Map