Data Driven Generation Siting for Renewables Integration in Transmission Planning

Prepared by:
Ty White, John Kuba, and Jason Thomas

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Section 1.0 -- Background & Purpose

Background

As public policy goals in the United States focus on increasing the penetration of renewable resources in the nation's energy mix, transmission system planners are tasked with developing expansion plans to ensure new transfer capacity is made available for these resources to access the market. An initial step in optimizing transmission expansion to support the integration of renewable energy is the identification of resource areas and the anticipated generation build-out associated with those resources.

Wind farms are often sited near existing transmission lines. This spatial correlation between wind energy development and existing transmission lines is demonstrable. Spatial data obtained from the Ventyx Velocity Suite, show 88 operational wind farm substations within the Southwest Power Pool's (SPP's) footprint. Of these 88 substations, 78.4% are within 5 miles of existing high-voltage transmission lines, and 96.5% are within 15 miles of existing high-voltage transmission lines. These data points graphed in Figure 1 below, underscore the importance of transmission proximity in planning and siting new wind developments. As such, transmission system planners are in a unique position to consider the development of new wind resources when planning transmission systems.

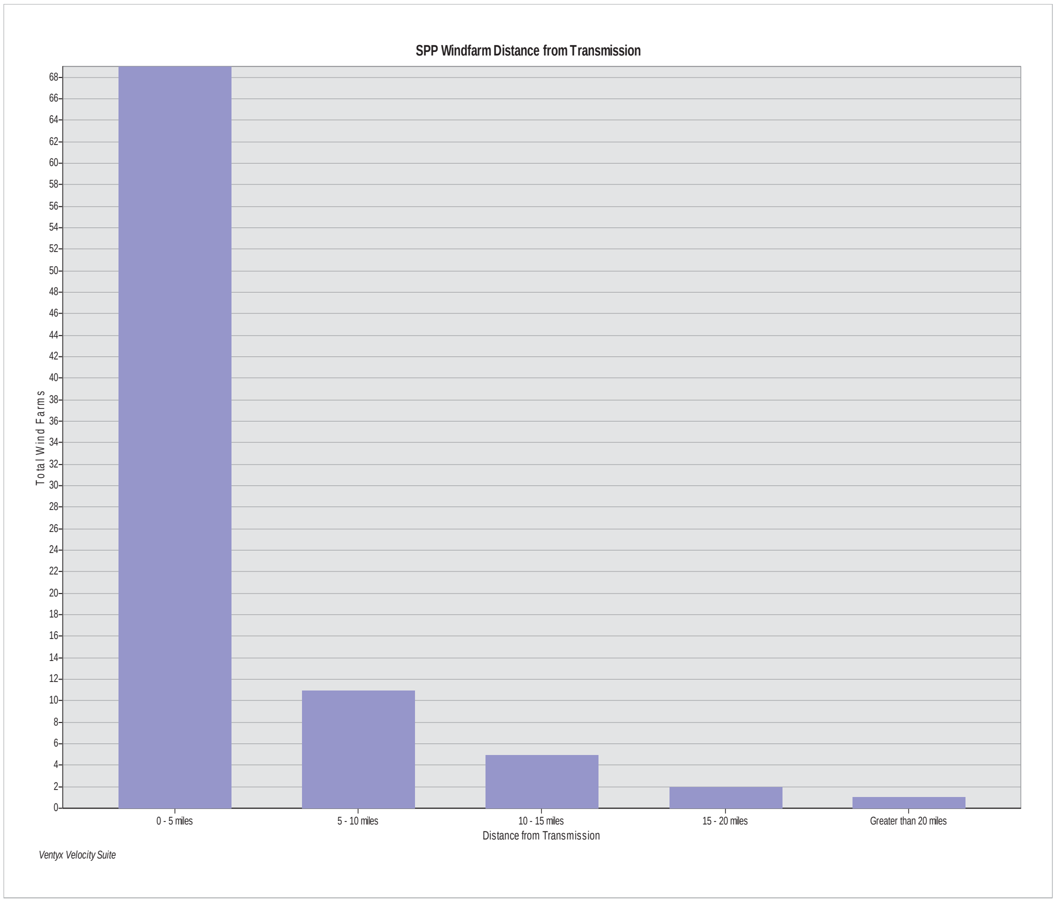

Figure 1: In SPP, 96.5% of wind farms are within 15 miles of their interconnection to existing transmission.

This document outlines a data-driven modeling approach called, The Landscape Optimized Wind Resource Environmental Siting (LOWRES) Model. LOWRES serves as a methodical process by which system planners can perform detailed analysis to identify priority wind resource zones leading to more efficient and precise transmission planning.

Purpose

This document illustrates a consistent and sound methodology to identify potential wind energy development zones using public geospatial data sets and Geographic Information Systems (GIS) software. This zonal approach can assist transmission planners in the optimization of new electric transmission facilities with respect to the most efficient and potentially least cost integration of wind energy resources onto the transmission grid. The model presented herein produces repeatable and defensible results based on a set of objective criteria.

Section 2 – Model Overview

Model Construction and Inputs

The LOWRES Model is comprised of the following inputs:

- Study Area
- 30m Digital Elevation Model
- Land Use Constraint Features
- Mesoscale Wind Maps
- Environmental Constraint Features
- Analysis Grid

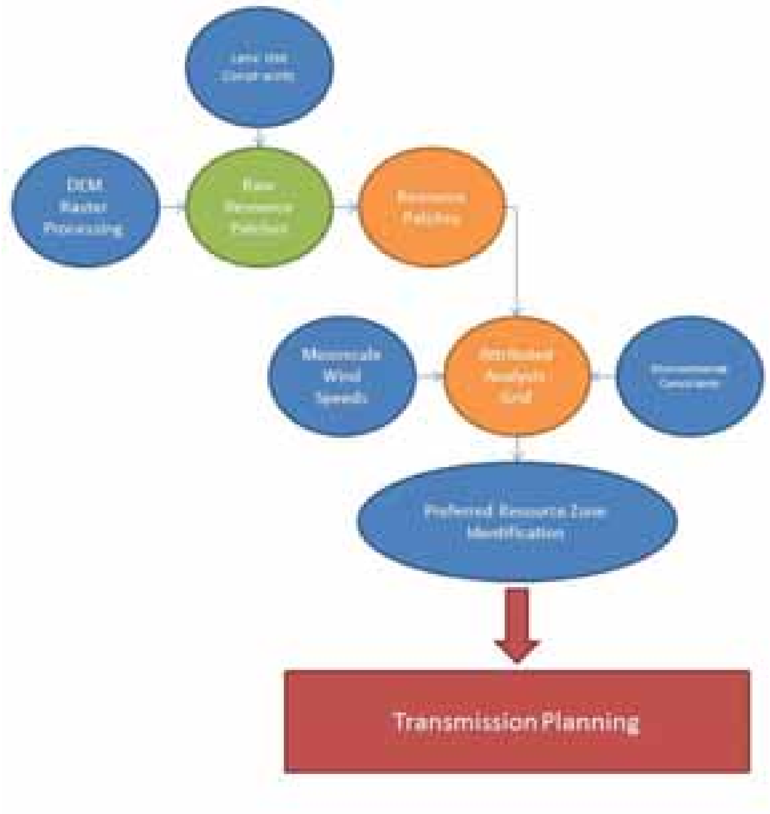

Figure 2: Conceptual LOWRES Workflow

2.1-- Raster Analysis

DEM Raster Processing

Computational Fluid Dynamics (CFD) methodologies and mesoscale wind maps assess specific resource sites and large regional resource areas; however, for landscape level planning of future transmission build out, these methods have their shortcomings.

Typical usage of CFD Models is extremely site specific (typically used to assess resources at a single wind farm site) and require long term meteorological field data in order to accurately model site feasibility. Also, CFD models require large amounts of computer processing capability and do not lend themselves to a landscape level analysis. These circumstances result in a very capital intensive analysis and require input information that is typically not publically available.

On the other hand, mesoscale wind maps are available from public sources, but these maps are very coarse (5km pixels) and while they do provide generalized meteorological data for a region, they do not lend themselves to analyzing and estimating potential capacity, and often are so coarse that they contain areas which are unsuitable for development.

The authors propose that for a true landscape level analysis of transmission build-out a surrogate data set should be created using processed Digital Elevation Models to assess wind exposure and isolate areas indicated on mesoscale wind maps as having economically viable wind speeds.

The National Renewable Energy Laboratory (NREL) Wind Resource Assessment Handbook recommends that potential wind resource areas with little or no relevant historical wind speed data be identified by seeking out topographic indicators in the landscape. Most important among these indicators are areas that are higher in elevation relative to their immediate surroundings, and thus have greater wind exposure. The LOWRES Model utilizes a raster processing script to iteratively analyze individual pixel values of USGS 30m Digital Elevation Models (DEM's) (See: Figure 3) to identify areas of higher relative elevation. The model's raster processing is approximated by the following formula:

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

Where:

x = any given cell in the input DEM raster

a = the mean elevation of all cells within an annulus with an internal radius extending 3 km from x and an external radius extending 3.06 km from x.

b = the mean elevation of all cells within an annulus with an internal radius extending 6 km from x and an external radius extending 6.06 km from x

c = the mean elevation of all cells within an annulus with an internal radius extending 12 km from x and an external radius extending 12.06 km from x

d = the mean elevation of all cells within an annulus with an internal radius extending 24 km from x and an external radius extending 24.06 km from x

*Note: Provided annulus distances translate to a pixel count from the focal cell (x) using a 30 m DEM. (i.e. 3km = 100 raster pixels.) Datasets with greater or less resolution may utilize alternate annulus distance approximations. A fruitful area of further research may include optimizing annulus distances as a function of local topography complexity.

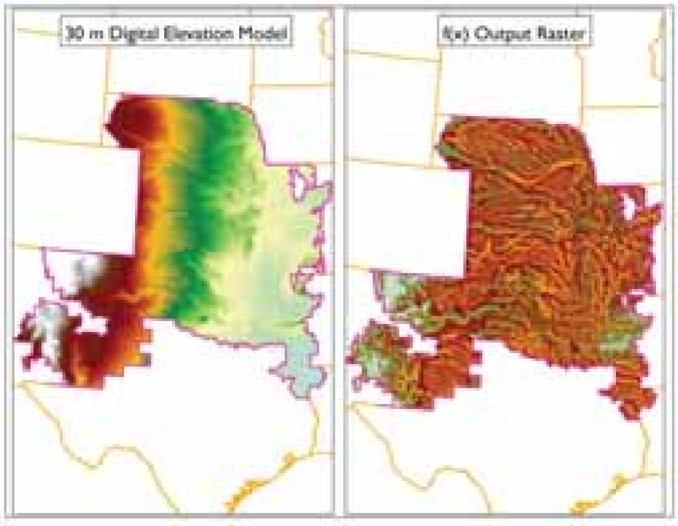

Figure 3: Input DEM Raster; 30m USGS

The processing output values provide a measure of each pixel's elevation relative to the immediate surrounding landscape. These values approximate the wind exposure at any given point in the study area. Generally speaking, output values above the mean raster value tend to be advantaged for wind exposure, while those below the mean raster value tend to be disadvantaged.

The authors hypothesized that examination of existing turbine locations should reveal a strong spatial correlation with areas on the output raster {f(x)} that have a value greater than the mean raster value, and that the correlation should become greater as the f(x) value becomes greater.

To test this hypothesis the authors calculated the f(x) raster for the entire Southwest Power Pool (SPP) footprint and analyzed the locations of 4,107 existing turbines in the following manner.

2.2 – Output Regression Analysis

At a conceptual level a raster represents a spatialized statistical dataset, allowing for statistical analysis of the raster values, and providing an opportunity for identifying spatial trends in statistically analyzed data. The authors utilized raster attributes by reclassifying the f(x) raster based on Standard Deviation δ-values, after which all 4,107 turbine points were attributed and tabularized with the δ-class in which they were located.

Table 1: Turbines per Sigma Class

Raster Class	% Of Total SPP Area	Total Turbines in Class	% Of Total Turbines Analyzed
-4δ	1.0%	0	0.0%
-3δ	1.7%	0	0.0%
-2δ	14.2%	5	0.1%
-1δ	34.8%	75	1.8%
1δ	34.3%	1278	31.1%
2δ	11.5%	2285	55.7%
3δ	1.1%	244	5.9%
4δ	1.4%	220	5.4%

A graph of Table 1 reveals that, though the Percentage of Total SPP Area for each δ-class is normally distributed, the Percentage of Total Turbines found in each class is shifted dramatically towards those areas on the map with higher f(x) values.

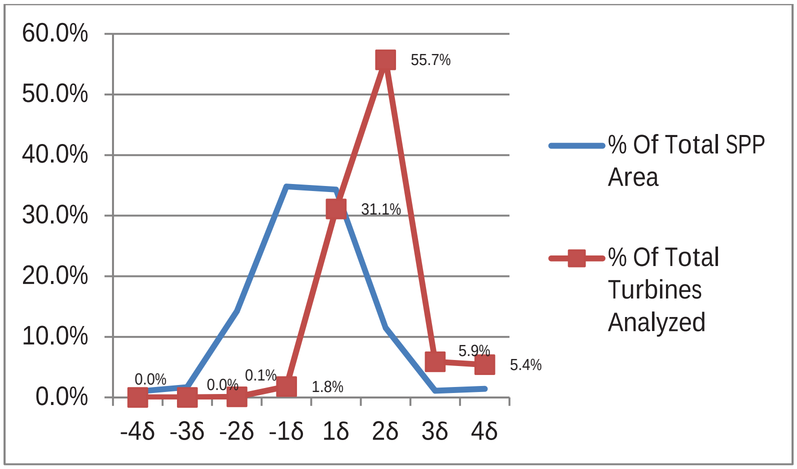

Figure 4: Percent of Turbines found in each Sigma Class

The above graph does seem to indicate a precipitous drop in the 3δ and 4δ categories; however, whether this is caused by poor resource in these areas or if the relative rarity of total turbines in these classes is a function of the scarcity of available land requires additional analysis. Plotting the quotient of the "Percentage of Total Turbines Analyzed" by the "Percentage of Total SPP Area" (Turbine Density) for each class reveals that when normalized for the total land area available to the 3δ and 4δ raster classes, Turbine Density is on par with the 2δ class, and even greater than the 1δ class.

Table 2: Turbine Density by Sigma Class

Raster Sigma Class	Turbine Density
-4δ	0.00
-3δ	0.00
-2δ	0.01
-1δ	0.05
1δ	0.91
2δ	4.84
3δ	5.36
4δ	3.86

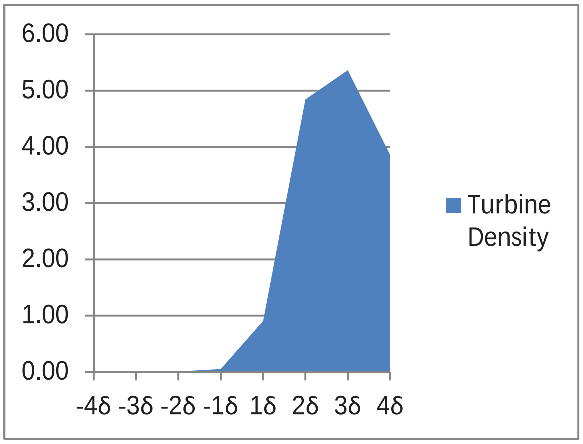

Figure 5: Turbine Density by Sigma Class

The results of this analysis confirmed both the authors' hypothesis, and the assertion by NREL that areas of higher relative elevation serve well as an indicator for wind exposure in a desktop landscape analysis, therefore providing a means to bound suitable wind farm development areas within a given regional meteorological regime in an efficient way.

Section 3 – Model Application

Raw Resource Patch Extraction

Raw resource patches can be developed by isolating those pixels which have an f(x) value in the δ-classes deemed most desirable. The authors propose that when evaluating any particular study area, analysts should choose δ–classes in which at least 95% of the existing turbines within the study area can be found. Once isolated, the desirable pixels are converted into a vector feature class termed "Raw Resource Patches" for further analysis.

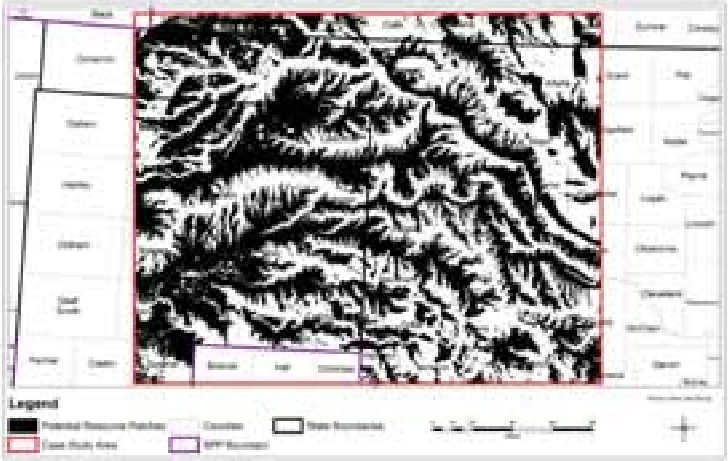

Figure 6: Desirable f(x) valued pixels, once isolated, become Raw Resource Patches.

Land Use Constraint Identification and Potential Resource Patch Development

Land Use Constraints are defined in this paper as geographic areas unsuitable for wind farm development due to regulatory prohibitions, construction infeasibility, or the presence of existing incompatible development. Land Use Constraints reduce the size of resource areas may that would otherwise be suitable for new wind development. Examples of land use constraints may include, but are not limited to, existing wind farms, restricted airspace, some public lands, lands used for recreation (parks, etc.), and areas of dense residential development. Because incompatible land uses are prohibitive to utility scale wind development, it is necessary to remove the overlapping portions of Raw Resource Patches from consideration to avoid over estimation of resource capacity potential in any given area. Once identified, Land Use Constraints can be merged into a single feature class and used to Erase the portion of the Raw Resource Patches that are unsuitable for development. The resulting output is referred to as Potential Resource Patches.

Construction of Analysis Grid

Once a study area has been defined, a standardized grid of polygon vector features is constructed. This relatively low resolution analysis grid is critical as it allows for the aggregation of much higher resolution data into standardized discrete features that facilitate equitable comparison of the resource in different areas of the landscape. Existing landscape divisions such as the Public Lands Survey System (PLSS) Township-Range boundaries may be used as an analysis grid; alternatively, a custom grid that better suits local geography or the scope and scale of the study area may be preferred, Figure 7 depicts a custom 4 mile x 4 mile grid. Once land use constraints are eliminated from raw resource patches, the remaining features need to be measured and aggregated to the analysis grid. Measuring the area of advantageous or “windy” land in each grid cell allows for the approximation of potential capacity. Typically, wind farms in the SPP footprint occupy 50-75 acres of windy land (including unused space for adequate spacing between turbines) for each megawatt (MW) of installed capacity. NREL assumes each square kilometer of “windy land” is capable of hosting 5 MW of installed capacity (49.4 acres/MW)

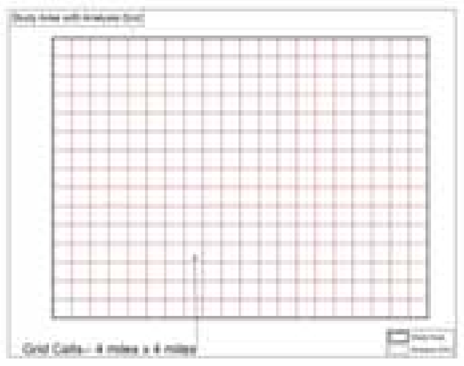

Figure 7: Example Analysis Grid

Landscape Environmental Constraint Identification

While Environmental Constraints do not necessarily eliminate a particular geography from wind development, they can increase permitting complexity and the risk of pursuing development. Sensitive species habitat and large wetland complexes are examples of landscape level environmental constraints. Diligent research should be committed to identifying environmental constraints, and collecting/creating spatial data layers that effectively represent the distribution of sensitive resources in the study area. Methodologies to identify potential constraints should consider the following:

- Regulatory Compliance
    - Endangered Species Act
    - Migratory Bird Treaty Act
    - Bald and Golden Eagle Protection Act
    - Clean Water Act
    - State Natural Resource Regulations
- Guidance Documents
    - US Fish and Wildlife Land-Based Wind Energy Guidelines
    - AWEA Wind Energy Siting Handbook
    - Eagle Conservation Plan Guidance
    - State Issued Guidance Documents and Best Management Practices
- White Papers, Academic Studies, and Various Conservation Initiatives, Local Permitting Restrictions

Identified Landscape Environmental Constraints are aggregated to the analysis grid as a percentage of the total analysis grid cell encompassed by environmental constraints.

Wind Resource Identification

The wind resource for individual grid cells should be assessed with the highest resolution data available. Ideally, wind data would be physically collected by operational met towers located in the defined study area. However, met tower data is typically private, proprietary information that is seldom publically-available. Furthermore, this data is very geographic specific, making it less likely to provide adequate spatial coverage for a landscape level analysis. As an acceptable substitute, the author recommends public mesoscale wind data to assess potential wind resource across the study area.

The LOWRES Model attributes each Analysis Grid cell with a mean or range of wind speeds as indicated on public or commercial wind maps. Topographic advantage and wind exposure as discussed in Section 2.1 and 2.2 does not automatically confer economical wind resource to support development, the LOWRES Model seeks to identify those regions with the best wind exposure that are also coincident with regional meteorological conditions capable of supporting wind farm development.

Resource Zone Identification

The LOWRES Model output is an Analysis Grid defining the potential installed capacity as a function of total acreage of advantageous topography, mesoscale wind speeds, and percent coverage of environmental constraints. The authors propose using these criteria to select clusters of grid cells called “Resource Zones”. The output “Resource Zones” have the highest potential for future development based on the following:

- Maximum Potential Capacity

  Greater windy land availability increases the probability that wind projects will have sufficient capacity to optimally utilize new transmission infrastructure.

- Maximum Mesoscale Wind Speeds

  Greater wind speeds increase the economic viability of future wind projects, thereby increasing the probability they will be pursued to completion and minimizing costs to consumers.

- Minimum Coverage of Environmental Constraints

  As previously discussed, the presence of environmental constraints presents financial and permitting risks to new wind projects. Resource Zones with fewer or no environmental constraints are less likely to result in environmental impacts or increased permitting costs for new wind developments.

Section 4 – Conclusion and References

Conclusion

LOWRES illustrates one method to identify potentially suitable geographic areas for wind energy production, or Resource Zones, using public geospatial data sets and GIS modeling. Ultimately the LOWRES Model is constrained by the data inputs, and is intended for the purpose of identifying large Resource Zones with an increased probability of wind development build out in the event that transmission capacity becomes available. Future research and development of the Model may include assigning variable priority values to f(x) raster δ-classes, and prioritizing landscape environmental constraints to better represent the risks associated with each constraint found in the study area. However in its current form the model's output can assist transmission planners by providing defensible approximations of the potential location, economic feasibility, and capacity of future wind generation within a given study area leading to the planning and design of an optimal transmission network.

References

Ventyx Velocity Suite, 2014

Wind Resource Assessment Handbook; NREL; AWS Scientific, Inc.

Estimate of Wind Land Area and Wind Energy Potential by State, for areas >= 30% Capacity Factor at 80m; NREL; AWS Truepower

National Elevation Dataset; USGS