The University of Texas at Austin

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Wind Energy Suitability Analysis in Texas

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GIS & GPS Applications in Earth Sciences (27460)

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Background and Problem Statement

Wind Energy has increasingly become a part of the U.S. and Texas's energy mix. In fact, Texas in ranks first in the nation in wind energy production, total wind capacity, and in number of turbines (EIA, 2019). Some key drivers that contribute to Texas's wind development include: Federal subsidies, renewable portfolio standards, production tax credits, investments of almost $7 billion in Texas transmission lines, and low barriers regarding the transportation of parts thanks to the expansive road network (Linowes, 2018). Statista (2021) reports that as of 2020, wind energy made up 23% of the total Texas electricity generation and is only expected to grow. To see areas most likely to contribute to further wind turbine development, ArcGIS will be used to answer the question – which areas in Texas are the most suited for wind energy production?

The table below outlines the criterion for suitability in this analysis. Least to best suited areas are given a rank from 1-4 and areas where construction is not an option are given a rank of 0. The areas excluded from any suitability ranking are protected lands and areas within a certain radial distance of airports. For the rest of the categories, ranks of 0 were not attributed since factors like better technology or increased investments can affect the cutoff for what is considered 'well-suited'.

Rank	**Wind Speed**	**Slope**	**Protected Areas**	**Population density**	**Airport buffer**	**Transmission Buffer**
0	-	-	Yes	-	1.8 nm	-
1	<5.8 m/s	<10 ˚	No	100000	1.8-3.6 nm	7800 m
2	5.8-6.5 m/s	8-10˚	No	10000	3.6-4 nm	4700 m
3	6.5-7.5 m/s	7-8˚	No	1000	4-5 nm	1000 m
4	>7.5 m/s	<7˚	No	0	5-6 nm	450 m

Rasters will be generated (6 total) for each category with a rank value depending on its attribute. They will then be summed up using Map Algebra. Areas with the highest values will correspond to the best suited areas. Range of values will be from 0-20.

Data Collection

The table below summarizes information on the data gathered.

Dataset	Source	Details	Datum	Accuracy	Year
Windspeed	Global Wind Atlas	Raster	WGS_1984	0.0025 dd	2022
Elevation	USGS	GTOPO 30	WGS_1984	0.0083 dd	2022
Population density	Texas Tech GIS	TIGER feature class	WGS_1984	-	2010
Airports	Texas Tech GIS	STRATMAP shapefile	WGS_1984	-	2002
Transmission	Oak Ridge Lab	Shapefile lines	WGS_1984	-	2022
Protected Areas	Lab 1	Shapefile - polygons	GRS_1980	-	
Turbines	USGS	Shapefile - points	NAD 1983	10 m error	2022
Texas Boundary	Texas Tech GIS	TIGER shapefile	WGS_1984	-	2010

Windspeed / Global wind atlas: https://globalwindatlas.info/

Elevation / USGS: https://earthexplorer.usgs.gov/

Population Density, Airports, Transmission , Texas boundary/ Texas GIS Data: https://hifld-geoplatform.opendata.arcgis.com/datasets/geoplatform::electric-power-transmission-lines/about

Protected Area: In class Lab

Turbines: https://eerscmap.usgs.gov/uswtdb/data/

Data Pre-processing

Windspeed data was gathered from Global Wind Atlas, with values in m/s at different heights from 10m, 50, 100m, 150m and 200m. The 100m windspeed values were downloaded as a raster after analyzing the 2022 wind turbine data. As seen in figure 3 below, the wind turbine attribute table has a column for hub heights (t_hh), but many values were -9999 m. In order to find which height was best to evaluate windspeeds, this column was exported to excel. Then, values that were negative were excluded from the analysis, and an average height value was extracted. The average height was 82.2 m, and since wind turbines are only becoming taller, the 100 m height was selected for the windspeed raster.

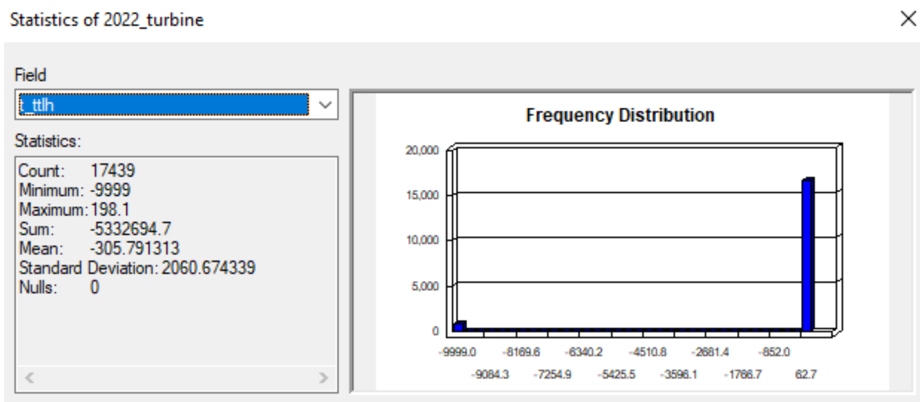

Figure 3. Hub height distribution

Elevation Data was gathered to find the slope of the terrain. To do, GTOPO30 data was downloaded from USGS. The grids did not cover the entirety of Texas, so two girds covering the left and right hemispheres of Texas were downloaded and loaded onto ArcMap, Figure 1 below shows the grids. Using the "Mosaic to Raster" the two halves were merged and then were extracted using "Extract by Mask". Then the merged elevation rasters were used create a slope raster using "Slope" under spatial analyst. Last, the windspeed raster had a cell size of 0.0025 x 0.0025 dd to the Elevation data was resampled to 0.0025 in order to match the two rasters. TIFF➔ Mosaic to Raster ➔ Extract by Mask ➔ Slope➔ Resample. This final raster was used in Analysis.

Transmission lines, Windspeed, and Wind Turbine locations had spatial extents that exceeded that of Texas, so the "Extract by Mask" tool was used with 'Texas Shape' file. Unzip➔ shapefile ➔ Extract by Mask. These final shapefiles were used for analysis. Figure 2 shows the unclipped raster of the windspeeds.

WGS_1984 was chosen as the geographic coordinate system since it was most frequent. Layers with different coordinate systems were transformed using the "Project" tool. Protected Areas and Wind turbines had to be transformed. Unzip➔shapefile➔Project➔load to ArcMap.

With these final versions of the rasters and shapefiles, Windspeed, Slope, Population density, Airports, Transmission, Protected Areas, Turbines, and the Texas Boundary were loaded onto ArcMap.

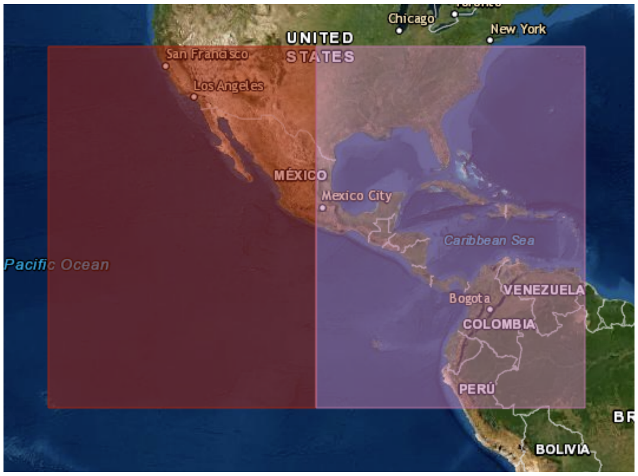

Figure 1. GTOPO30 elevation(USGS)

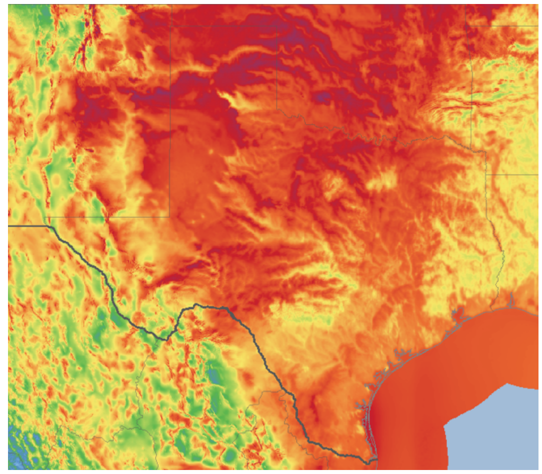
Figure 2. Windspeeds (globalwindatlas)

Date Processing and Analysis

The general workflow is shown below. Airports and Transmission have suitability dependent on distance to their locations. Wind and Slope are ranked by their existing raster data. Population has a correlation between density and construction. Protected Areas are not suitable.

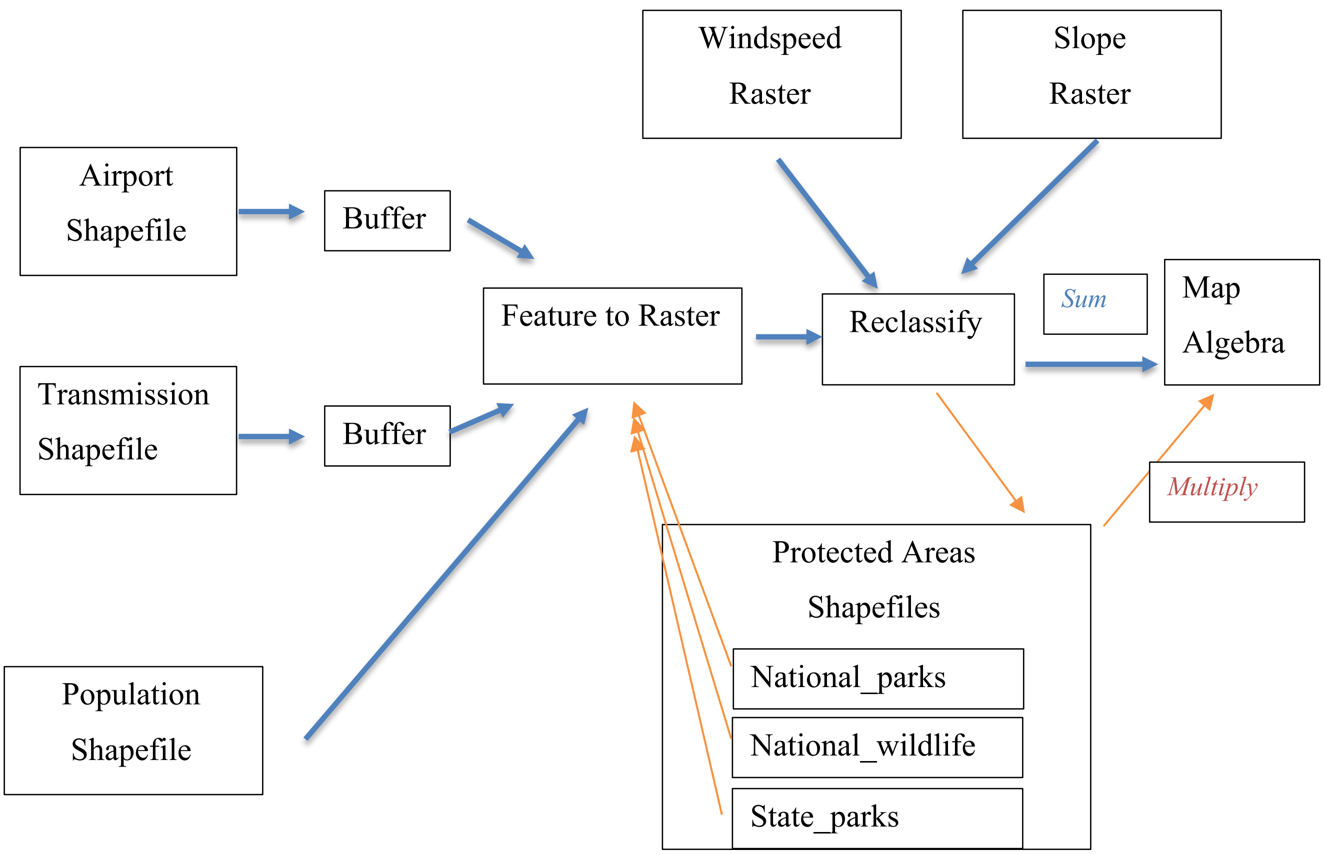

Figure 3. Workflow

Wind Speed was a straightforward Reclassification. Values were determined from the EIA (2022) saying utility scale wind energy requires speeds of at least 5.8 m/s. High value was determined from a research where 7 m/s was determined to be significant enough to have good capacity (Li & Miller, 2014).

Slope was also a straightforward Reclassification from the slope values. Values were determined from the same research by Li & Miller (2014).

Protected Areas were comprised of 3 separate polygon shapefiles. These went through the procedure of shapefile➔ Feature to Raster➔ Reclassify➔Map Algebra. During the reclassification process, any value that had a feature were given a rank of 1 and NaN values were given a rank of 0. This was intended to be multiplied by the final raster so that after adding all the suitable areas, all values will be multiplied by 1 or 0 (where the land is protected).

Population density showed a high correlation to the construction of wind turbines; However, distribution was difficult to measure because of the extremely populated cities verses the rural 0 population areas. To estimate cutoff values, population areas near the coast were evaluated. Figure 4 shows areas where turbines were built overlapping population density neighborhoods, and these values showed that very few exceeded or were around 1000 people. The rest of the ranks increased in magnitudes of 1 as an approximation.

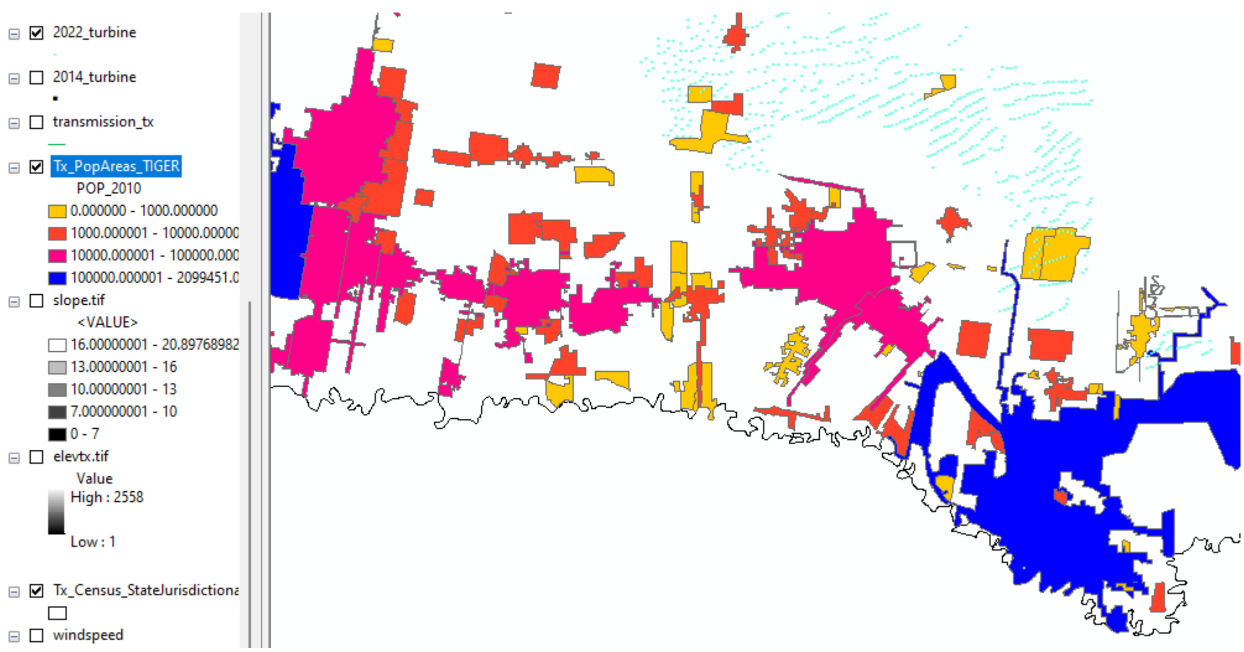

Figure 4. Population density near Texas Coast and Wind Turbine locations

Airport buffer values were extracted from a siting guidebook. Wind turbines should not be closer than 1.8 NM of an airport. At the 80 m height, they should not be closer than 3.6 NM and at the 200 ft height, they should not be closer than 7 NM(Barrett, DeVita, & Lambert, 2014). Buffers were assigned at each radial distance as seen in Figure 5. Buffers were made individually, but next time the “Multiple Ring Buffer” tool should be used. The process for this file went shapefile➔Buffer➔Feature to Raster➔Reclassify➔Map Algebra. Because each buffer was made individually, each buffer had to be added to make a final Airport buffer ranked raster. The furthest radius assigned a rank of 4 to all values. Then each buffer was assigned a value of -1 inside the circle and 0 for NaN values. This way when added, each ring decreased in rank until the center most ring had a value of 0 (4-1-1-1-1). Figure 6 shows a visual. Also, important to note, the raster made from the inner most radius of 1.8 NM was added to the “Protected Areas” since it has a ranking of zero. This raster will be added, but protected area will be multiplied, making rank 0, do not construct areas.

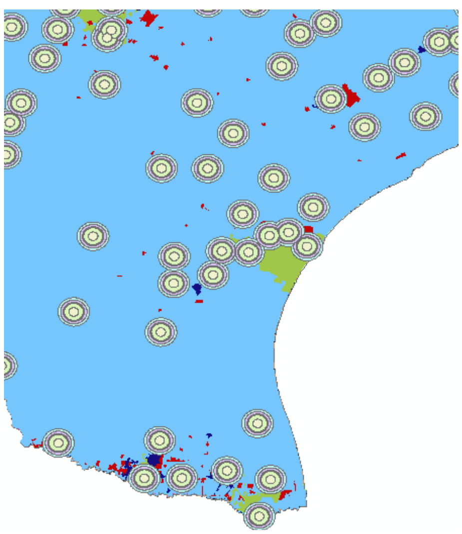

Figure 5. Multiple Buffers around Airport. Centermost will have rank of 0.

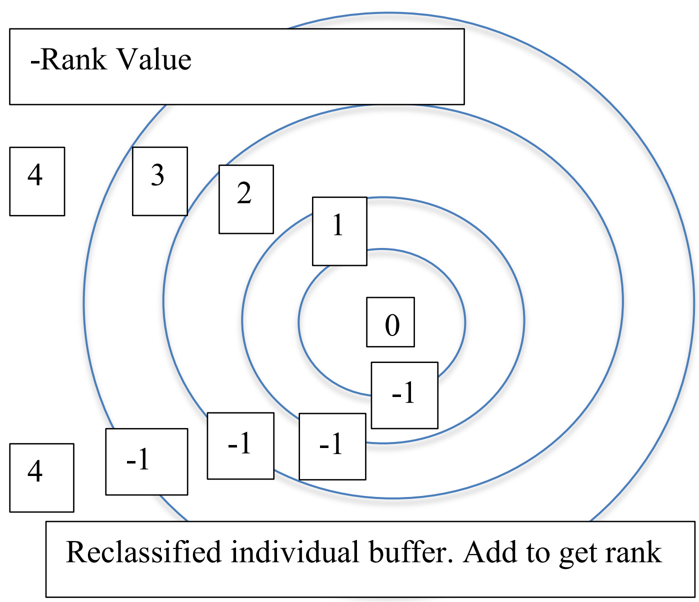

Figure 6. Reclassify/Ranking for Buffers

Last, Transmission Buffers were created. The rank cutoff for these were created by evaluating different distances of transmission lines to wind turbine locations using “Selection” ➔ “Select By Location”➔ Select from turbine ➔ Source from transmission_tx➔within a distance. Then by going through multiple distances and dividing the “Count” that pulls up from the Selection Statistics from the total number of turbines, a fraction of the total wind turbines showed that they existed within x distance of the transmission lines. Figure 7 shows an example of the count of turbines that exist within a 1000 m of the transmission. 4362/17439 (the total number of turbines shows that 5.7 % of all turbines exist within 1000 m. The ranks 1-4 represent the P10-P25-P75-P90 values.

Transmission line buffers took a similar approach to that of the Airport buffers i.e. shapefile➔Buffer➔Feature to Raster➔Reclassify➔Map Algebra. However, unlike the airport buffers where closer proximity meant a smaller rank, proximity to transmission lines warrant a greater rank. So values at each buffered distance were reclassified as a 1 and NaN's as a 0. As the rastered 1 and 0 transmission buffers added up in Map Algebras, distances that were overlapped increased by 1 close to the line, and distances far out had a value of 1. No 0 values were attributed because while efficiency and cost decreases with distance, it is not a parameter that entirely excludes itself as a site.

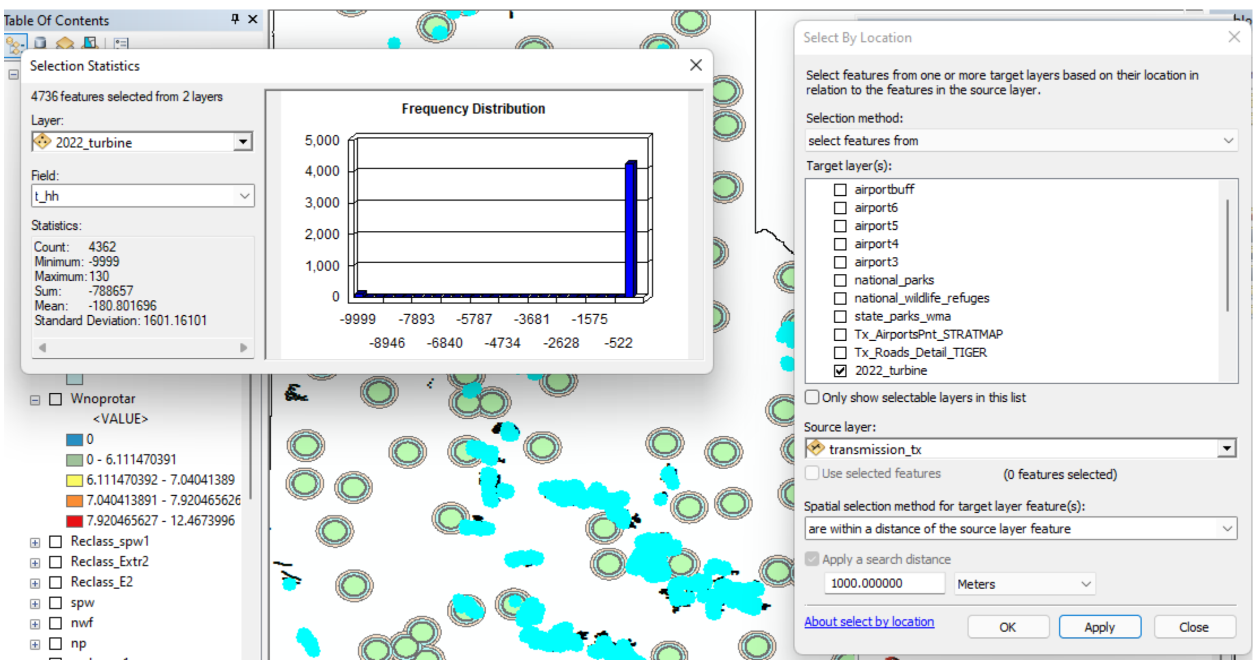

Figure 7. Count of turbines within a certain distance from transmission

Figures 8-14 below show various rasters created.

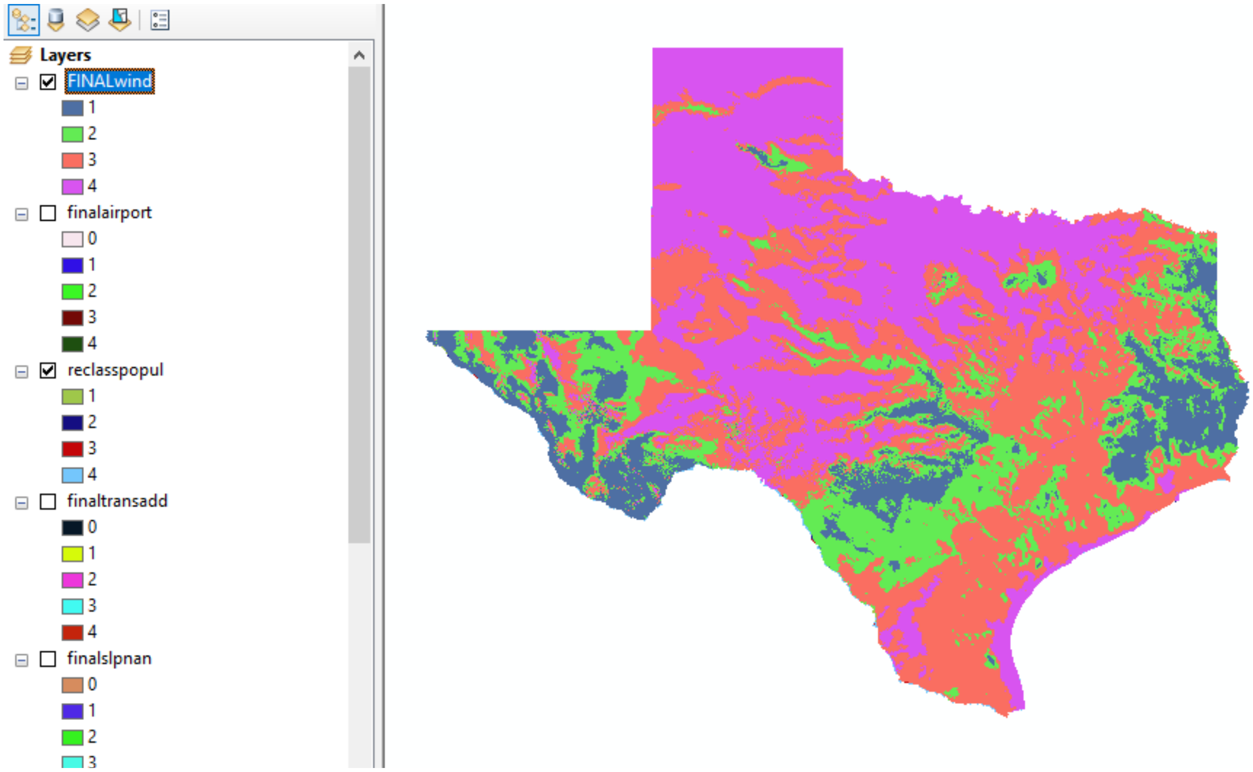

Figure 8. Wind speeds reclassified

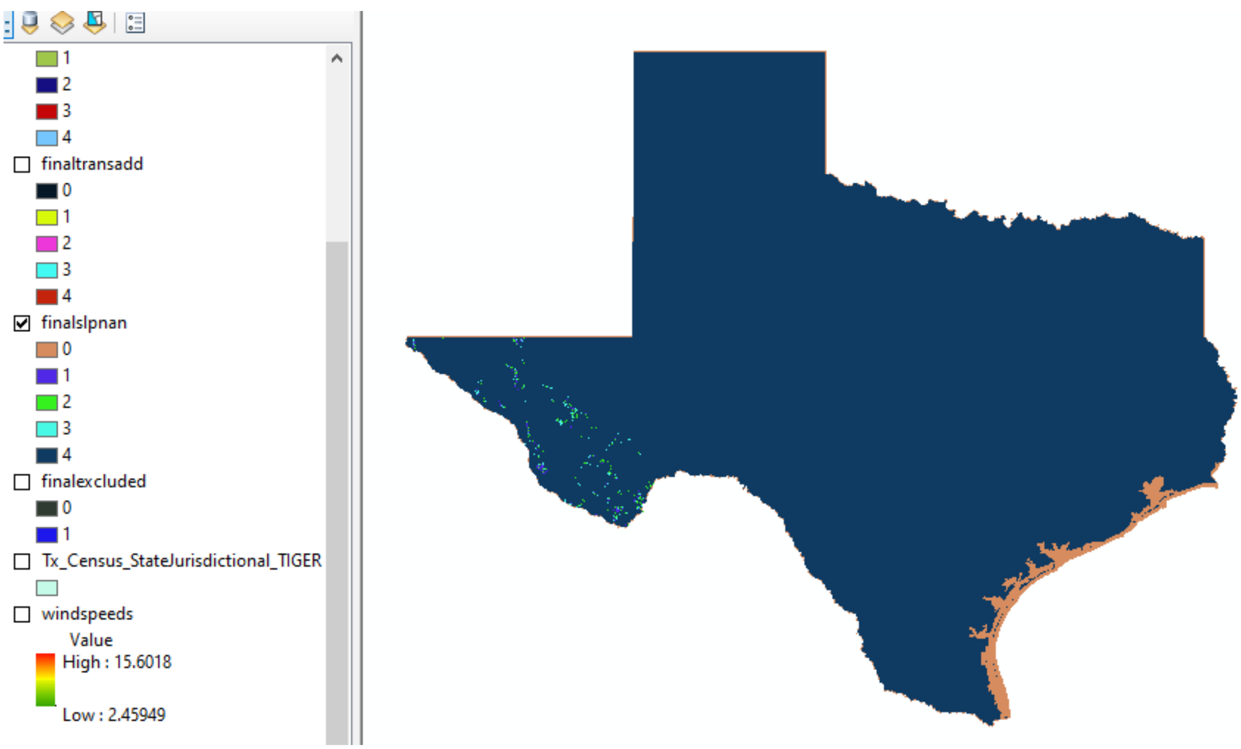

Figure 9. Slope reclassified

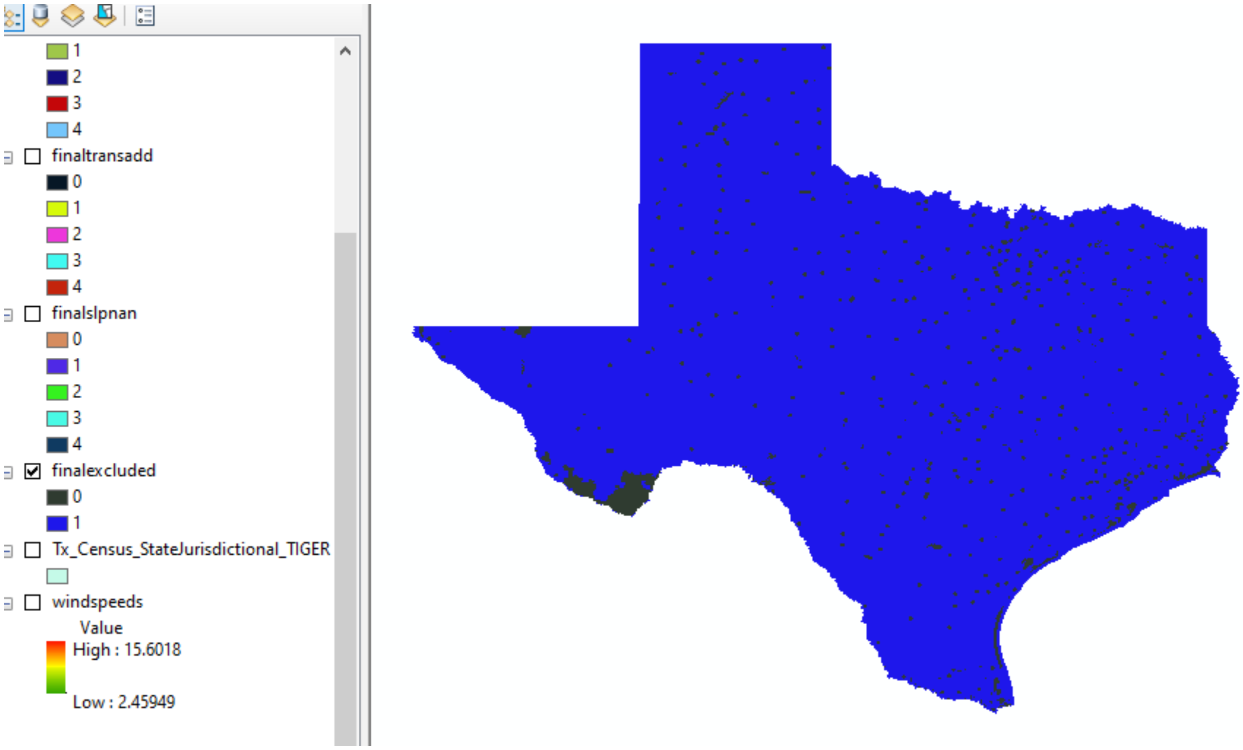

Figure 10. Excluded zones reclassified. Note it's just 0 and 1 to be multiplied later

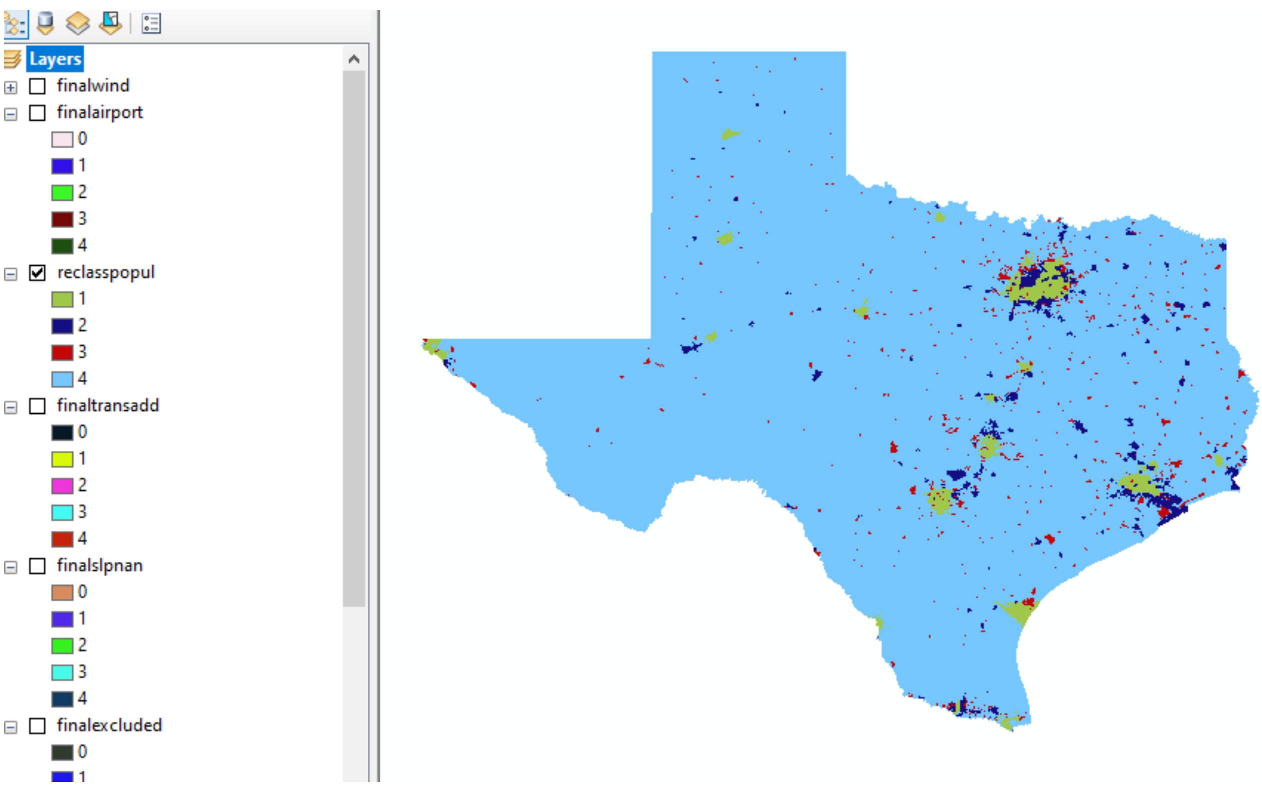

Figure 11. Population Zones reclassified

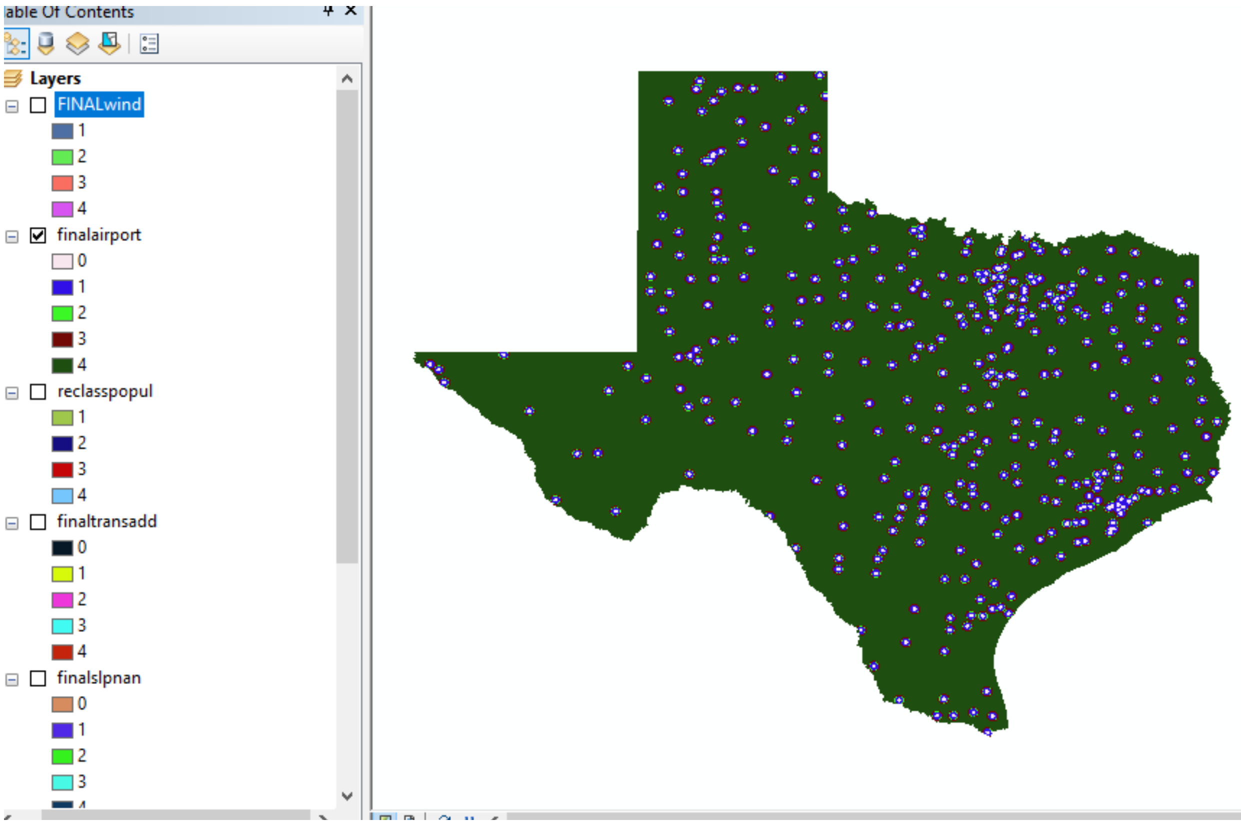

Figure 12. Airport buffer reclassified

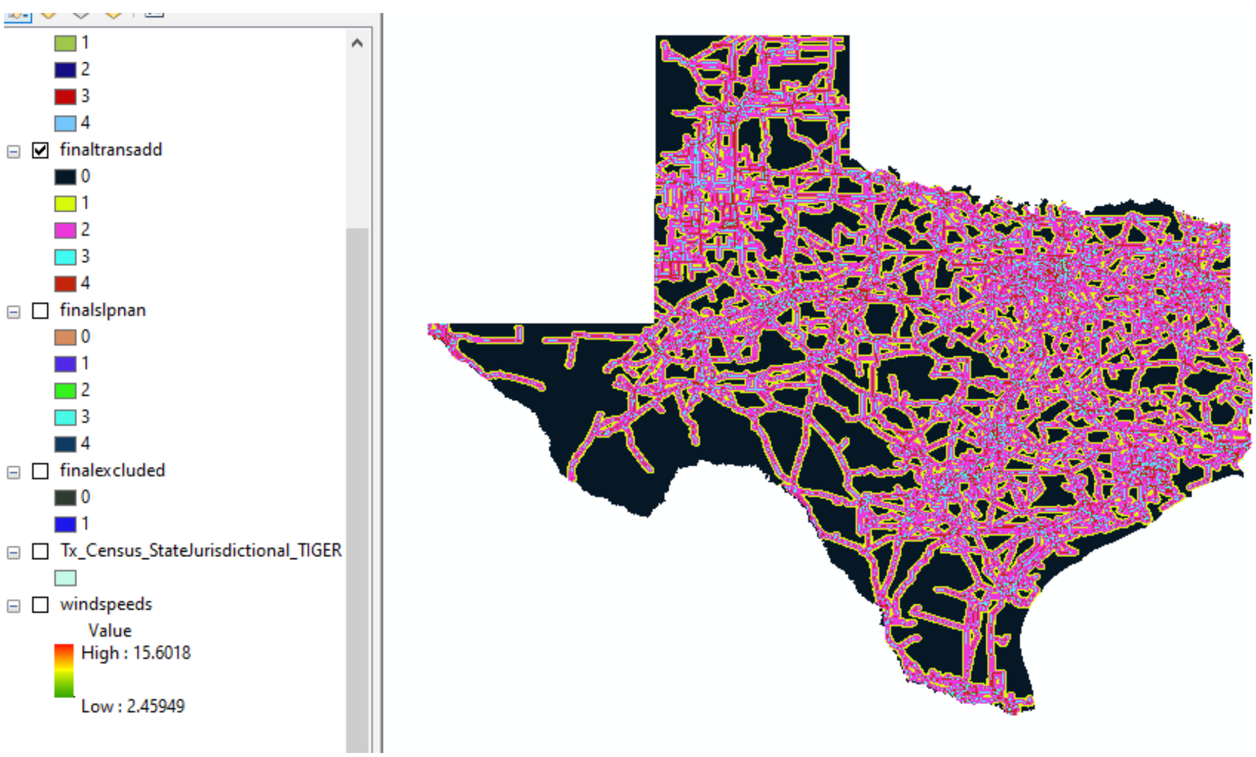

Figure 13. Transmission buffers reclassified

Final Map Algebra

1. Wind Speed
2. Slope
3. Protected Area (reclassified as binary)
4. Population Density
5. Airports
6. Transmissions

Eq.1 Final Raster = (1+2+4+5+6) * 3

Figure 14 shows the result of combining all the rasters. Figure 15 shows the result if windspeed was weighted 2 times greater than the rest. The first case shows much heavier dependency to transmission lines, likely because of previous investments that funded the expansion of the transmission lines that grew alongside the growth of building more turbines.

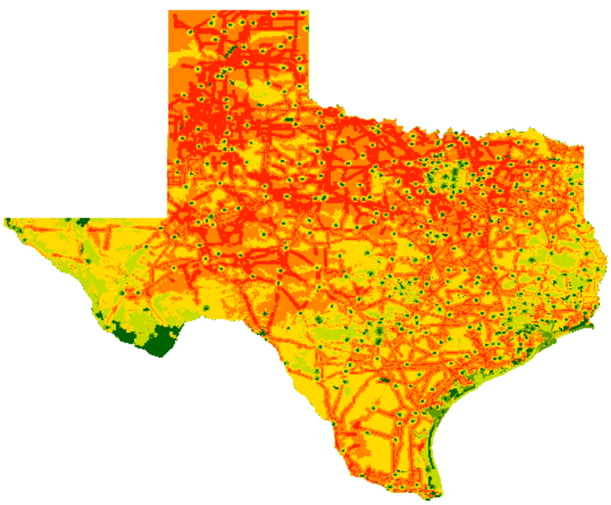

Figure 14. Final Raster as Eq. 1 shows

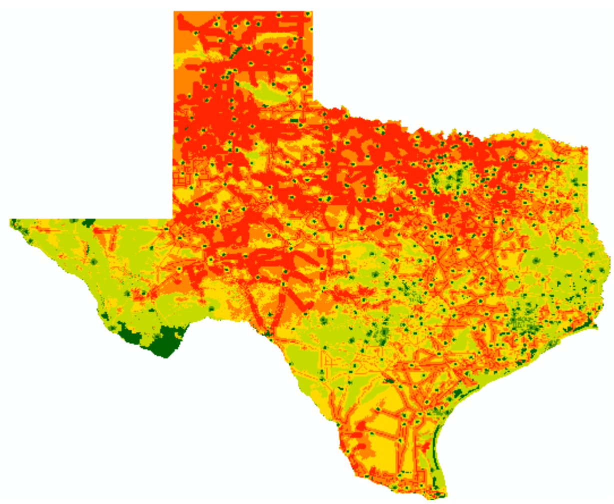

Figure 15. Final Raster Windspeed has 2x weight

Figure 14 is more realistic because the transmission lines are existing infrastructure that would reduce cost in future constructions. However, Figure 15 might be more realistic if looking at long-term suitability assuming that factors like transmission infrastructure will continue to increase.

Data Presentation

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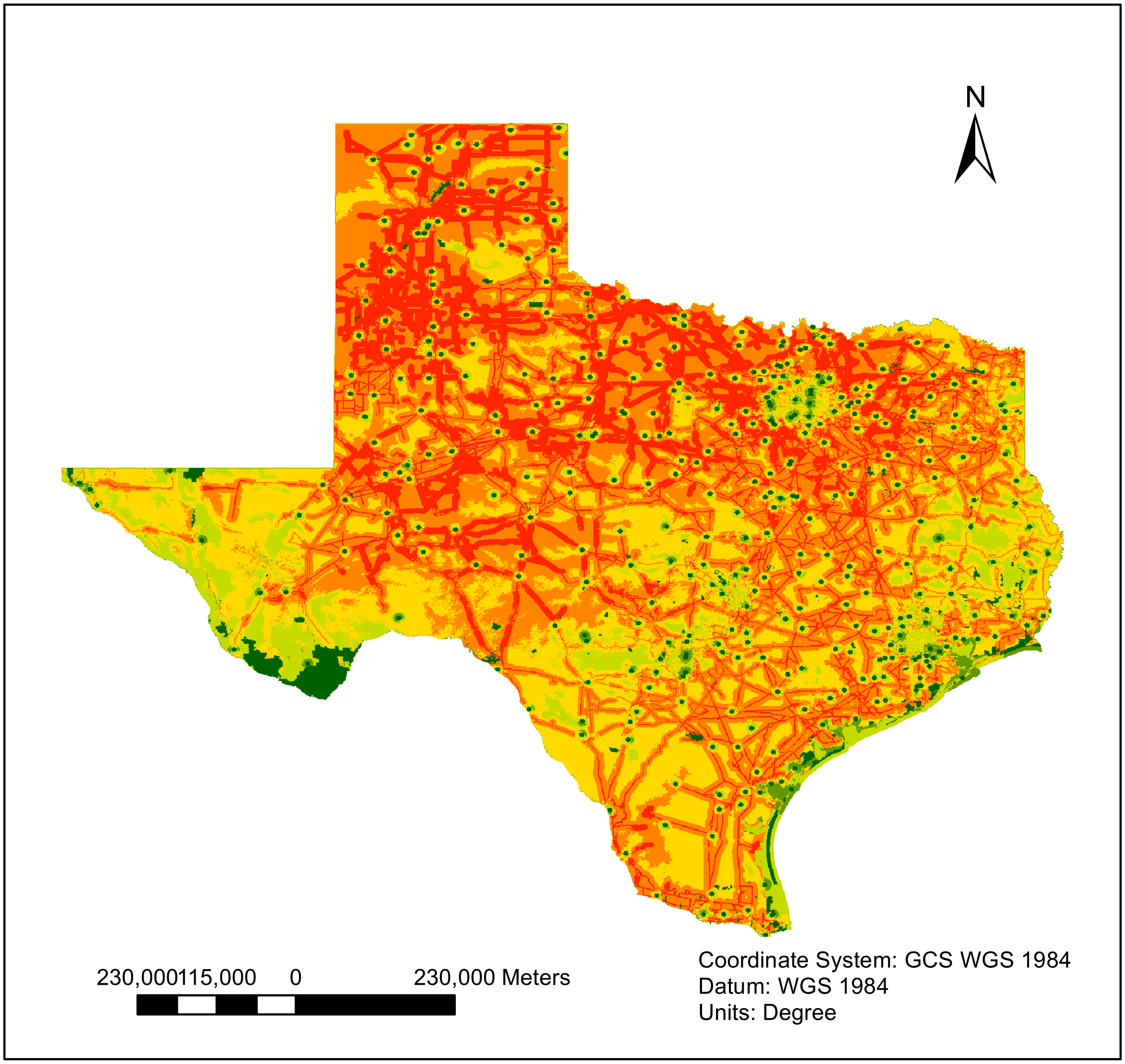
Regional Suitability Analysis of Wind Energy in Texas



Legend

Rankings for Wind Capacity

Value

- 0 : Not Suitable at all. Cannot Construct Turbines
- 0 - 11 : Least Suitable
- 11 - 13 : Low-Medium Suiability
- 13 - 15 : Med-High Suitability
- 15 - 17 : High Suitability
- 17 - 20: Very High Suitability

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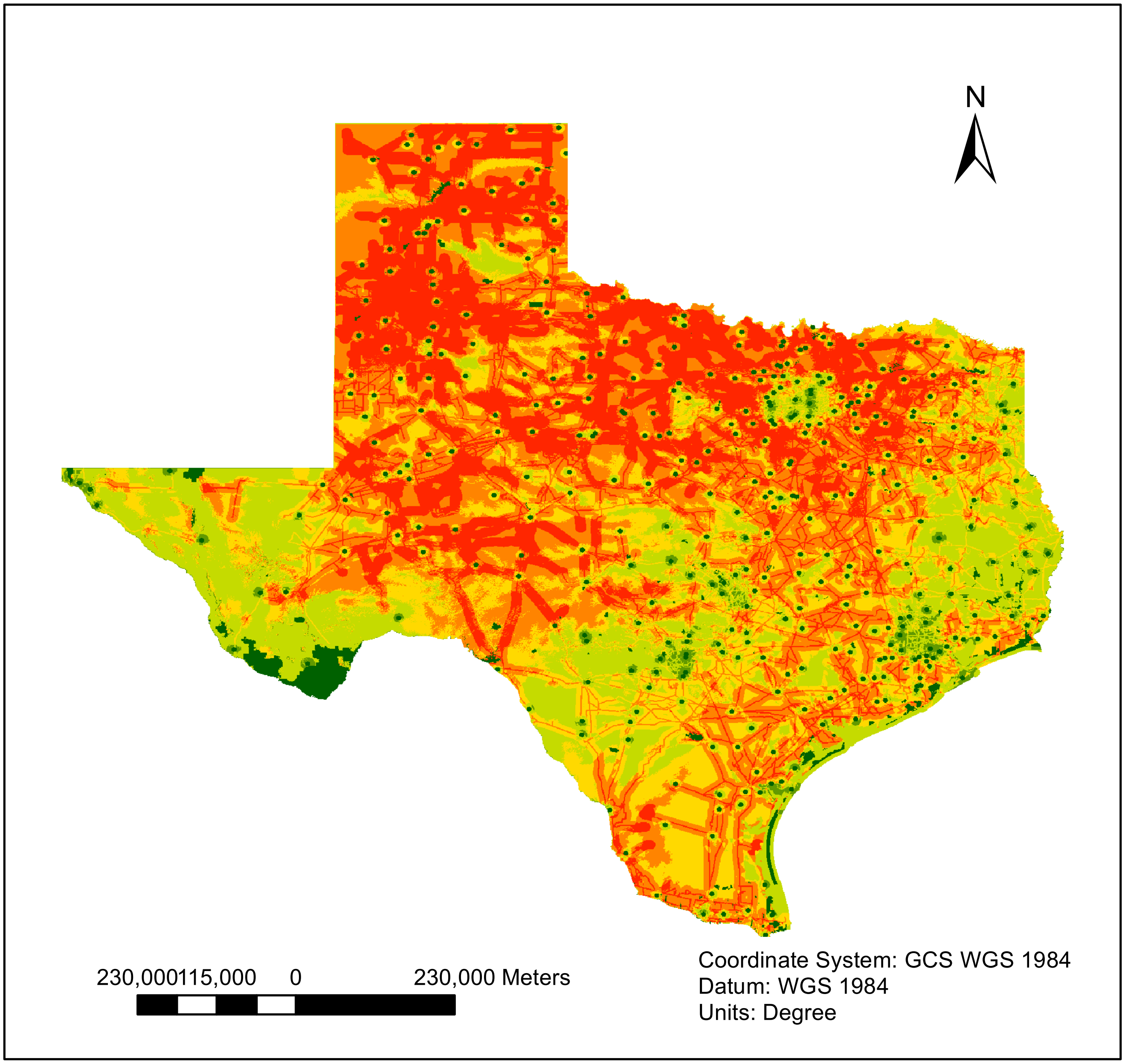
Regional Suitability Analysis of Wind Energy in Texas with Wind Speed weighted double



Legend

Rankings for Wind Capacity

Value

- 0 : Not Suitable at all. Cannot Construct Turbines
- 0 - 13 : Least Suitable
- 13 - 16 : Low-Medium Suiability
- 16 - 18 : Med-High Suitability
- 18 - 20 : High Suitability
- 20 - 24: Very High Suitability

References

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