A Spatial Analysis of Wind Turbines across the United States

By:

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Abstract:

Wind turbines, used to harness wind energy, have advanced significantly over the last decade within the United States increasing the wind capacity 30% year after year. Improvements in wind energy infrastructure have contributed to higher wind capacities, however, there are still barriers that challenge the overall effectiveness of wind farms. Additionally, wind energy continues to be one of the fastest growing industries. As of 2014, wind energy was the second largest form of renewable electric generation. Many researchers have argued that one of the main issues facing scientists and engineers must be finding a suitable location for wind turbines based off detailed spatial information (Diffendorfer et al. 2015). While the fight for an eco-friendlier environment remains a common goal, renewable electric generation could be a viable solution, so long as there is a suitable location to place wind turbines. Similar research suggests the implementation of GIS can be an essential ally in identifying ideal locations for these inherently geographic solutions for energy production (GeoMarvel, 2021). Suitable locations can be calculated through spatial analysis of geographic and cultural landscapes.

This paper will use a GIS framework to analyze land suitability for wind turbines based off the impact certain factors such as environmental, ecological, cultural, human settlement, and physical infrastructure have on wind turbine placement. More specifically differences in wind speed; distances from road network, urban areas, and differences in the topography of the land could prove to be the primary factors in determining land suitability for wind turbines across the United States. This study will take a GIS and programming approach to analyze various energy and geographic datasets. As a result, we will be able to see the various patterns in determining wind turbine placement and provide some useful information for planners and engineers to aid in decision making.

Introduction:

Decision-making regarding the impact's climate change has on the communities around the world may never be straight forward. However, one solution could be the development and implementation of more wind turbines as a source for clean renewable energy. To assess the effectiveness of certain environmental systems, increasing recognition of long-term sustainability in environmental management often requires consideration of socio-economic issues, including different methods and options that may be useful in aiding decision makers in those processes (Lovett et al., 2008). Some of those factors may include demographics and physical characteristics such as topography, or the distance between objects. As technology continues to improve, state and federal agencies have turned to mapping as an ally to identify plausible locations to place wind turbines for the purpose of this study, as a solution to an eco-friendlier environment.

For the decision makers at any level, there may be differing opinions, but the common goal sought by many how can was a society better improve the environment we live in today. Research surrounding this topic explains that wind energy has proven to be a viable option for renewable energy, but scientists and engineers suggest a few issues can make this transition difficult for decision makers. GIS, whether map making or through spatial analysis, has proven to be a useful tool in highlighting some of the issues decision makers face and how they be able to solve them (GeoMarvel 2021). This study uses a spatial programming approach through the GIS framework to address factors such as the impacts that certain demographics and physical characteristics like topography and distance between objects may have on wind turbine placement. The results of this study will hopefully provide some insight into decision making and being able to determine what may be the right locations to place turbines based of certain obstacles.

Materials and Methods:

This study used a GIS programming approach to analyze wind turbine data across the United States with a focus on the location and placement of wind turbines in the Texas Panhandle. Multiple datasets consisting of different geometry types were considered for this project. U.S. TIGER/LINE shapefiles from the United States Census Bureau were used for 2020 state and county lines all of which are polygon geometry type. For data about wind turbines across the U.S., this study pulled wind turbine shapefiles from the United States Geological Survey Data and Web services geodatabase. There were over a total of 60,000-point features within this dataset which represents active wind turbines. Airport (point geometry type) and primary road data (line geometry data type) were pulled from the Bureau of Transportation Statistics geodatabase in the form of shapefiles. Lastly, the USA major cities dataset came from the ESRI online geodatabase in the form of shapefiles. Due to available time, data used in this study was projected into the North America Albers Equal Area Conic projected coordinate system.

To carry out the programming functionally, this study used IDLE which runs python version three. Throughout most of this project, IDLE was used to create functions which can run a large amount of code all at once. Additionally, ArcMap and Jupyter Notebook were used to help formulate the scripts of code. For these functionalities to run properly within Python and ArcGIS, it was important to make sure the data was in shapefile format, because shapefiles store spatial data along with related attribute data. AcrMap was also used to create the cartographic maps and figures of the results. To analyze the various data used, several spatial geoprocessing tools had to be selected. The following flow chart explains the different geoprocessing tools selected for this study, along with a step-by-step process to ensure promising results were received:

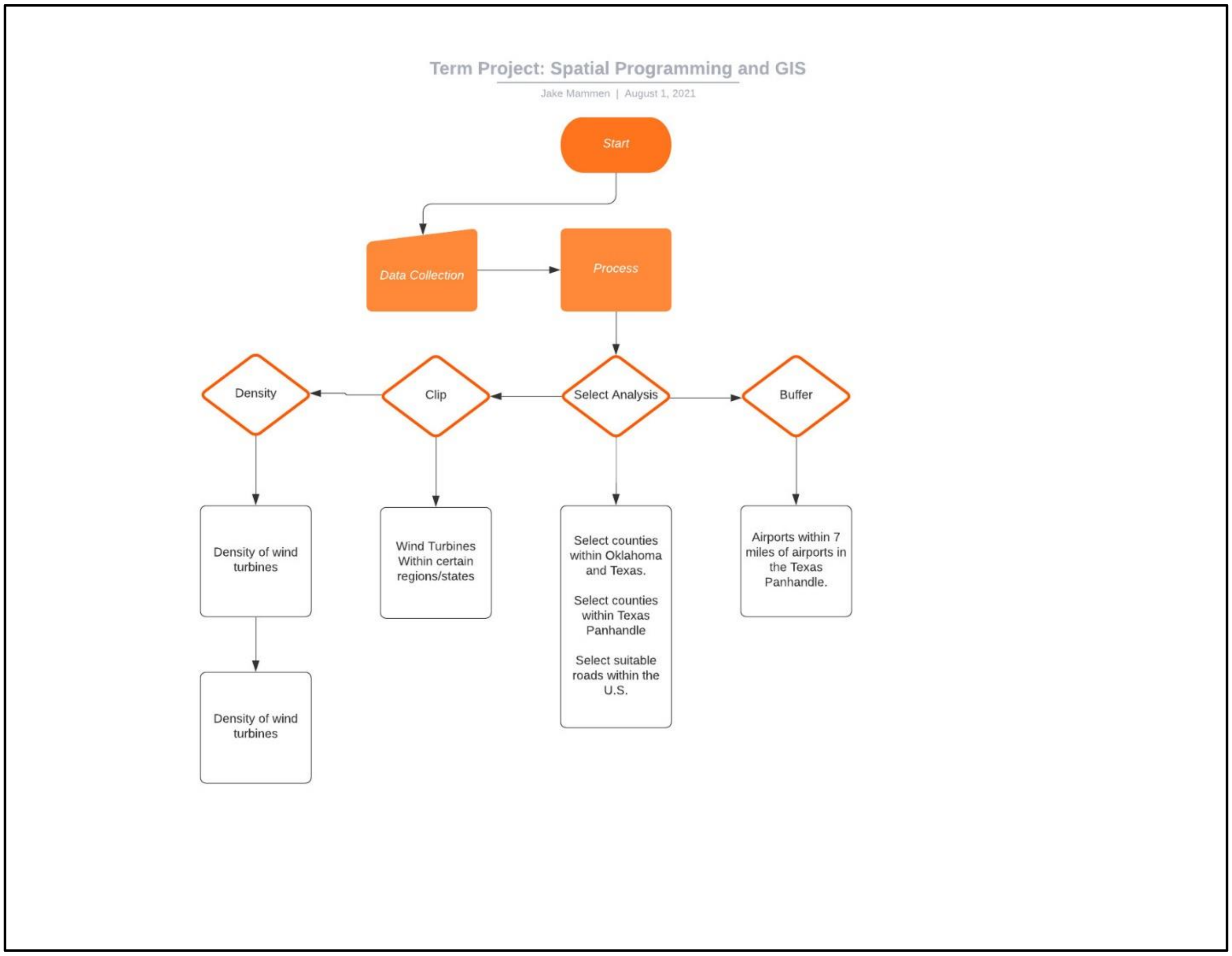

Figure 1. Flow chart of step-by-step processing, explaining the different geoprocessing tools.

After data collection, four different geoprocessing tools were selected to carry out the analysis. Given the rise in demand for clean renewable energy, the idea to build more wind turbines across the country is starting to become a reality. However, as stated above one of the biggest issues engineers and decision makers are facing is land suitability for wind turbines. First, both the wind turbine and airport datasets were imported into ArcMap to get an idea of how many locations and the patterns formed across the landscape. In Figure 2, the wind turbine data is mostly located within the United States with a few locations in the ocean.

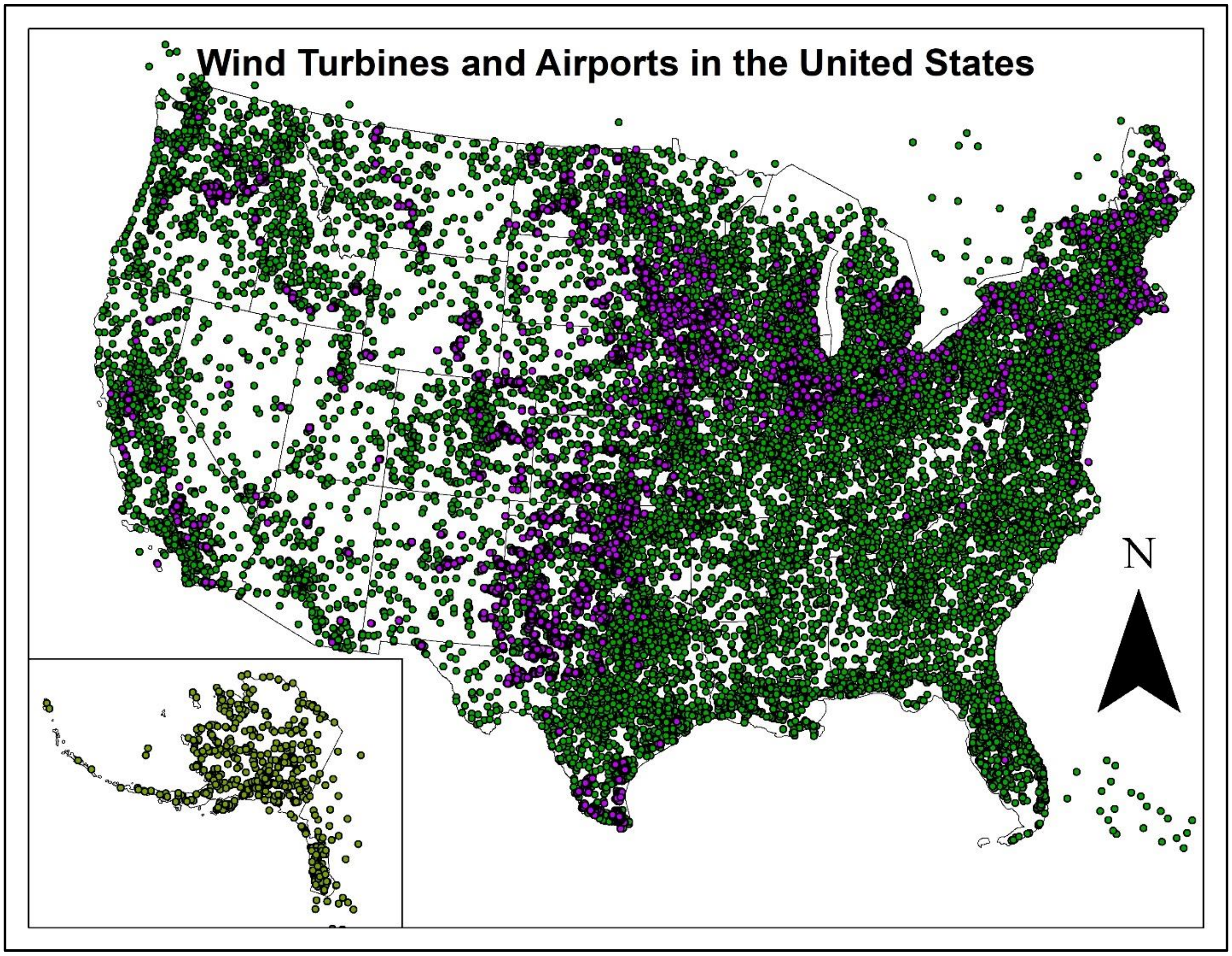

Figure 2. A map showing wind turbines and airports within the United States.

The purple-colored points are wind turbines, and the green colored points are the airports. Opposite of the wind turbine locations, there are many more airport locations within the United States and outside of the contiguous U.S. Since this study is focused on more of a central location, the first step in the geoprocessing workflow is to clip wind turbine locations and airport locations not within the contiguous United States. The geoprocessing function is written in such a way, it will allow the user of the program to select a clip function of either the wind turbines or airports. In this case, because there are more airports outside of the contiguous United States, clipping the airports feature layer should be sufficient. Once, those functions are completed, the program moves to the next geoprocessing function. Given the pattern the data presents in Figure 2, the geoprocessing program uses the point density function to better illustrate and pinpoint where there may be higher clusters of wind turbines and airports. The use of the density function was used for a better understanding of the issues decision makers and engineers face and with hopes of providing helpful information. The next step is to perform a series of different select and clip functions to narrow the study area down. The study area chosen for this project was the states of Oklahoma and Texas in the south-central plains. The reason for choosing these two states was because of the physical and demographic factors this region possesses. The landscape or topography across Oklahoma and Texas is generally flat with hardly any physical obstructions. Additionally, for clean renewable energy the plains provide an extremely windy environment at times which can generate a lot of wind power. Since, most of the land out in western Oklahoma and western Texas is farm or crop land the population is smaller than most metropolitan areas. The use of clip and select functions allows the program to cut down some of the data in each feature layer which provides a closer and more condensed analysis of the area. Through this series of select and clip functions the program takes the wind turbine data and clips out the wind turbine locations that don't fall within the Oklahoma and Texas state borders referencing the U.S. County shapefiles. Additionally, the program clips the airport data to fall only within Oklahoma and Texas. Then the program takes the U.S. County shapefiles and selects counties within the Texas Panhandle that has wind turbines in them. From there the airport dataset is clipped further to only show airport locations within those same counties with turbines in the Texas Panhandle. The last selection function to be executed is for the U.S. primary road shapefile to select suitable roadway across the country for a more general view. After the clip and select functions run, the buffer analysis remains the last geoprocessing tool within the workflow. Another big issue decision makers and engineers face when searching for suitable land for wind turbine development is proximity to airports or airfields (Rand et al. 2020). The buffer geoprocessing tool allows the user to see how close those wind turbines are to certain airports. This series of geoprocessing steps should provide a very useful set of results for decision makers and engineers to determine land suitability for future development.

Results:

When the geoprocessing program begins running the user is prompted to enter either a clip of turbine or airport feature layer. If the user enters clip turbine, the following output is seen in Figure 3.

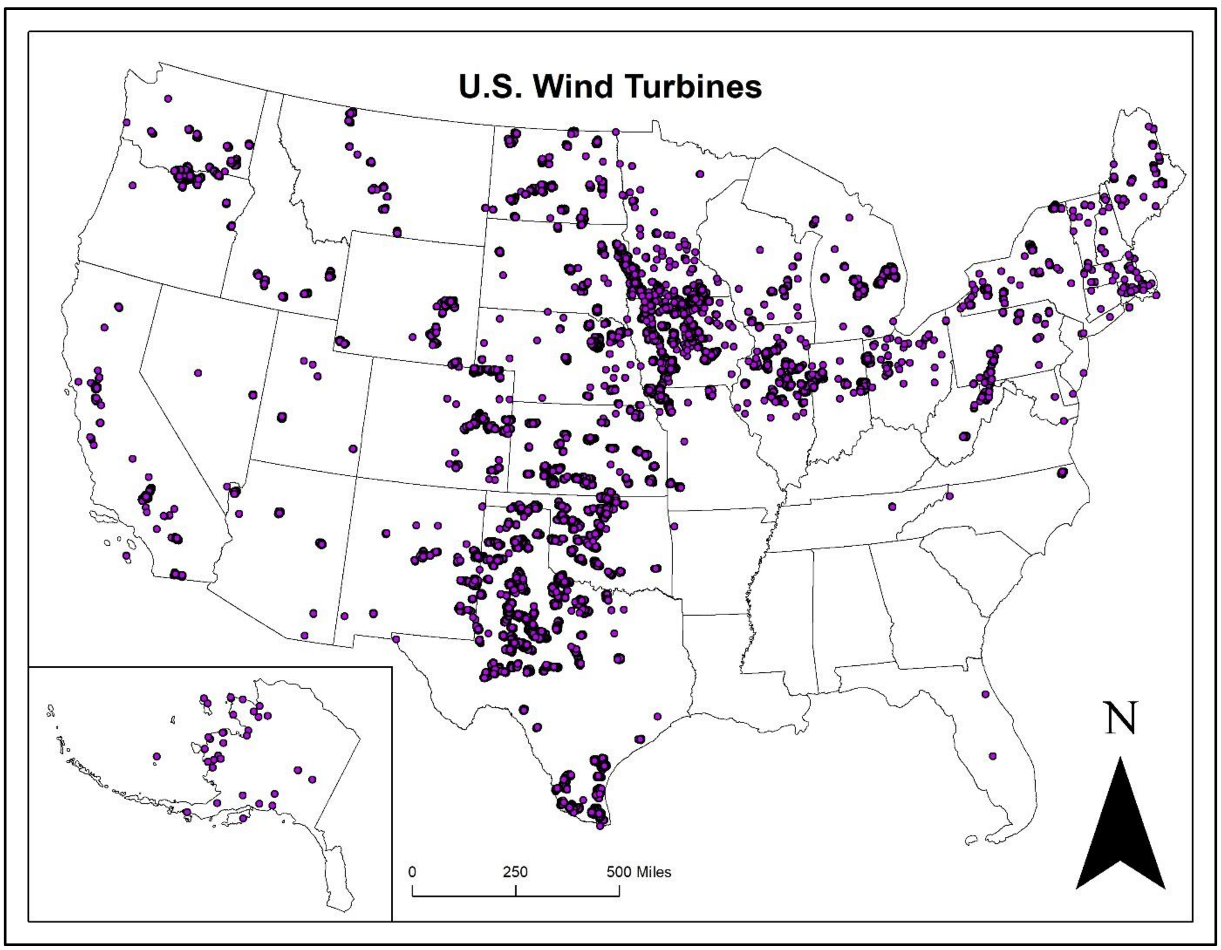

Figure 3. A map showing clipped wind turbines within the contiguous United States.

As discussed in the methods section, the result seen in the above output (Figure 3), there is not much of a change from the original feature layer. However, this result does present a more sufficient picture of wind turbines within the contiguous United States. Instead, if the user enters, clip airports, then the following result can be seen in Figure 4.

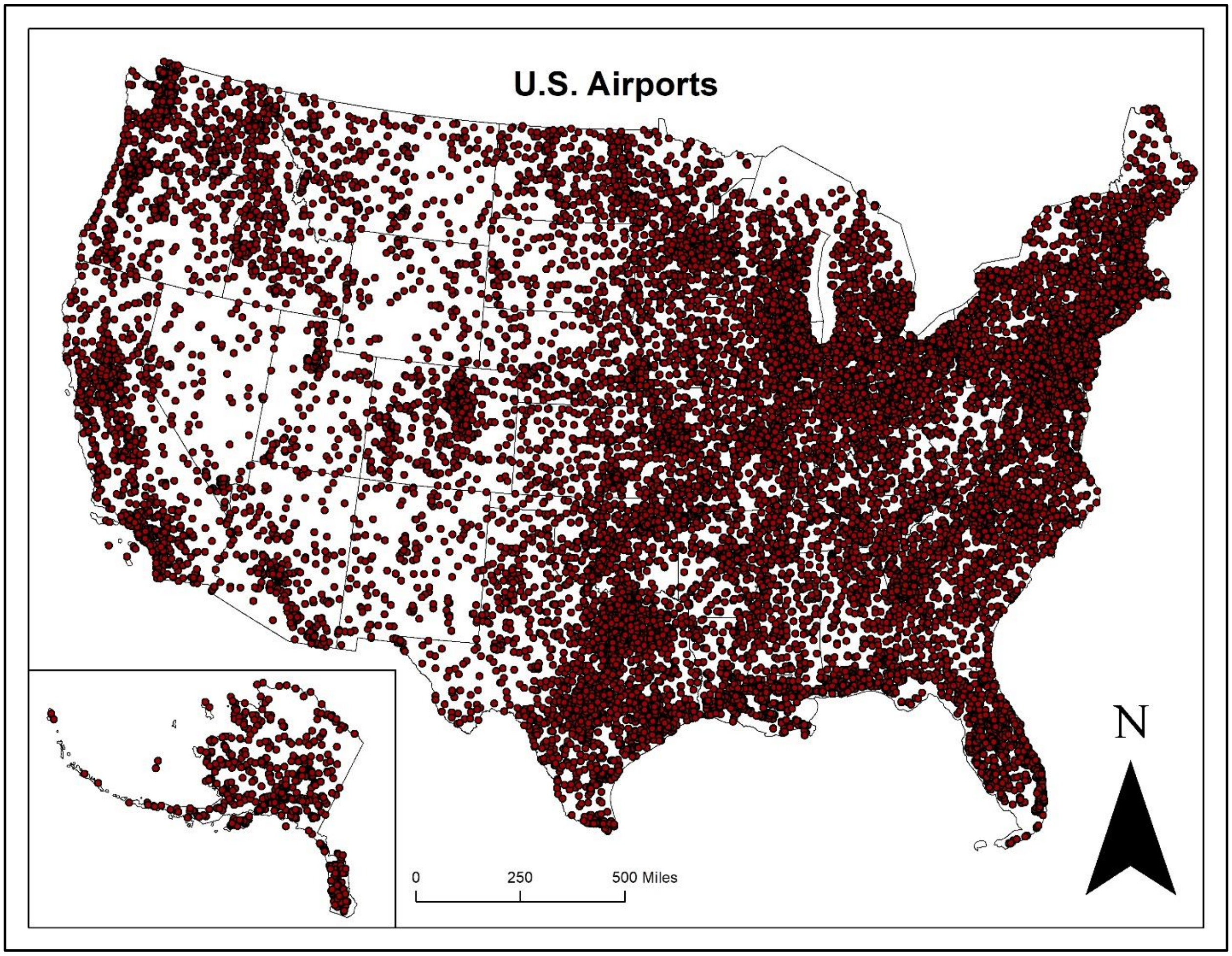

Figure 4. A map showing clipped airports within the contiguous United States.

When the clip was performed on the airports feature layer, the result is much more clean and easier to picture and draw conclusions from. This particular result compared to the wind turbines clipped feature layer, raises the question about land suitability. There is a clear patter between both the wind turbine clipped feature layer and the clipped airport feature layer. While there are far less wind turbine locations in comparison to airport locations, the clustering wind turbines seems to follow that of airports. Furthermore, using the point density function allows the user to perform what some scientific research or literature call a Hot Spot Analysis.

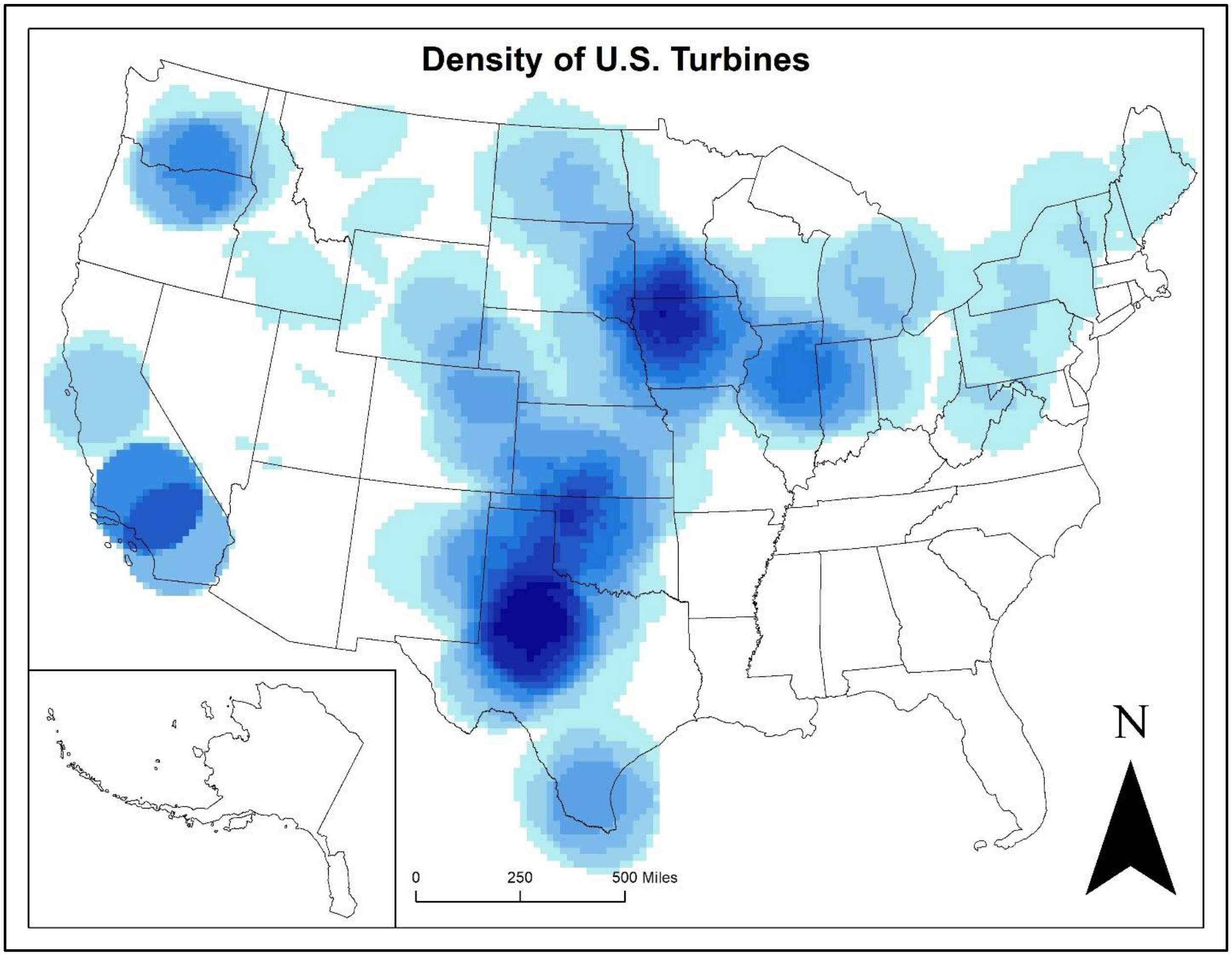

Figure 5. A map showing density of wind turbines within the contiguous United States.

As the program continues calling the geoprocessing functions, the point density function performed on the clipped turbine feature layer. The result of the output seen in Figure 5, suggests the clustering of wind turbines is highest within the Great Plains and upper Mid-West. The highest values indicated by the darker blue colors show where there are many wind turbines locations whereas the lighter blue colors show not very many wind turbine locations. After the program runs the clipped wind turbine feature layer through the point density geoprocessing tool, it runs the clipped airport feature layer.

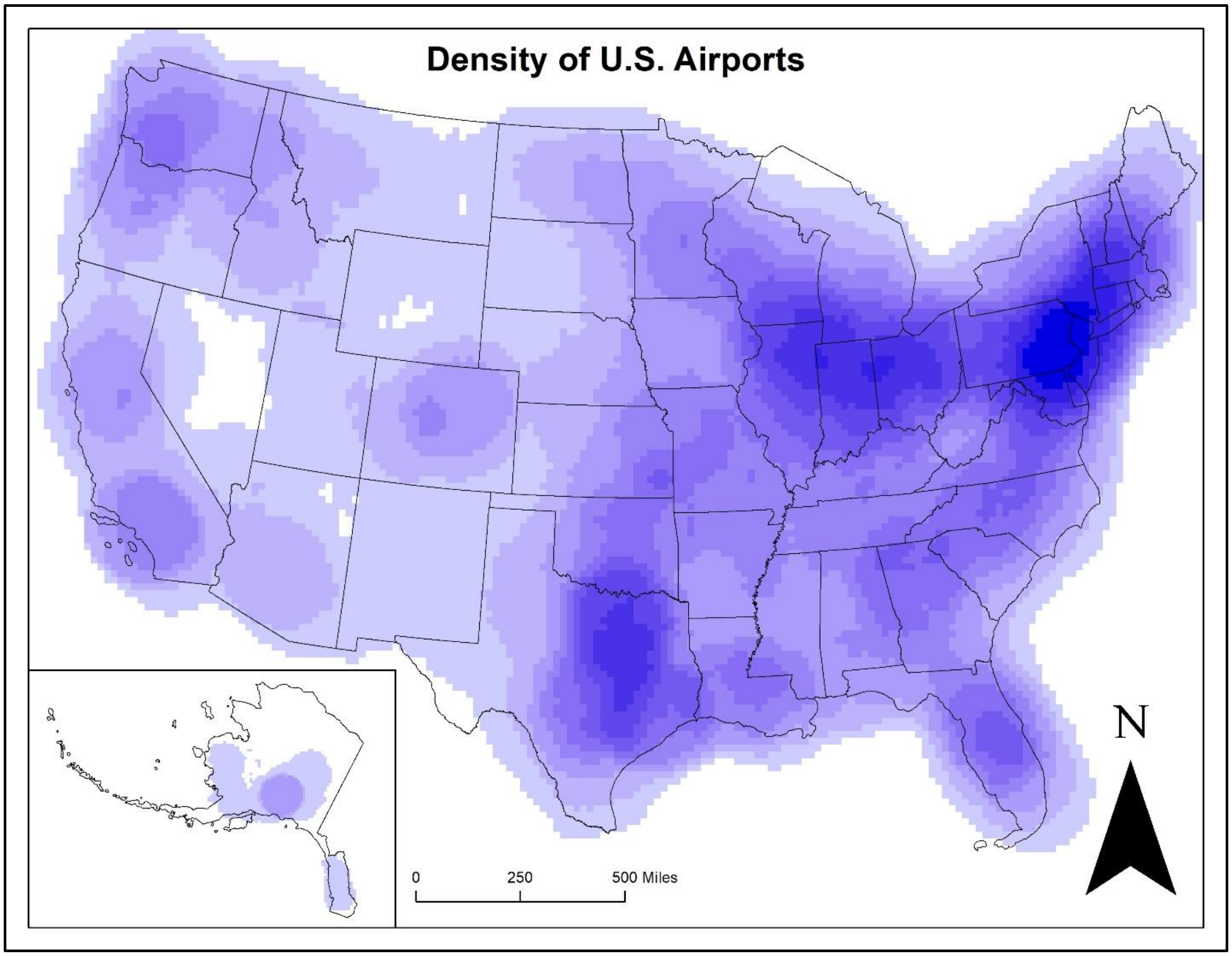

Figure 6. A map showing density of airports within the contiguous United States.

The density result from the clipped airport feature layer seen in Figure 6, is far different from that of the wind turbine density output. The darker purple colors indicate a higher number or clustering of airport locations whereas the lighter purple colors show less airport locations. This can be attributed to the amount of airport locations compared to the wind turbine locations. However, this result does provide some useful information regarding the patterns of wind turbine locations vs. airport locations.

After the point density geoprocessing tools run, the program moves on to calling the series of clip and select functions for the wind turbine, airport, U.S. County, and U.S. Primary

Road shapefiles. The following result in Figure 7, shows the higher clustering of wind turbines located in Oklahoma and Texas.

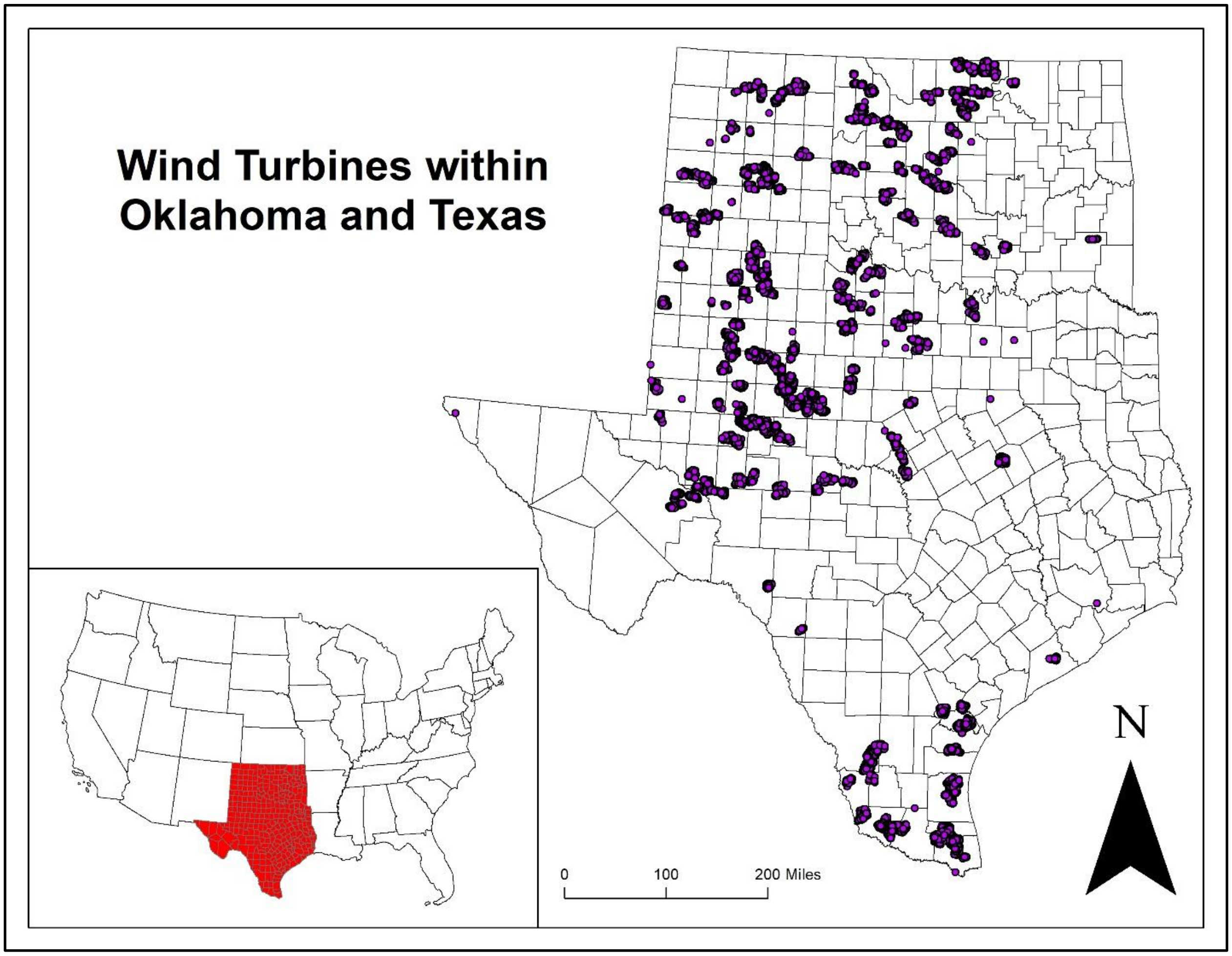

Figure 7. A map showing wind turbines within the Oklahoma and Texas region.

The program allows the user a closer look at the pattern seen here which provides useful information as to why wind turbines may be located in this region. Many of the wind turbines located in Oklahoma and Texas are located out west where they may not be very many physical obstructions.

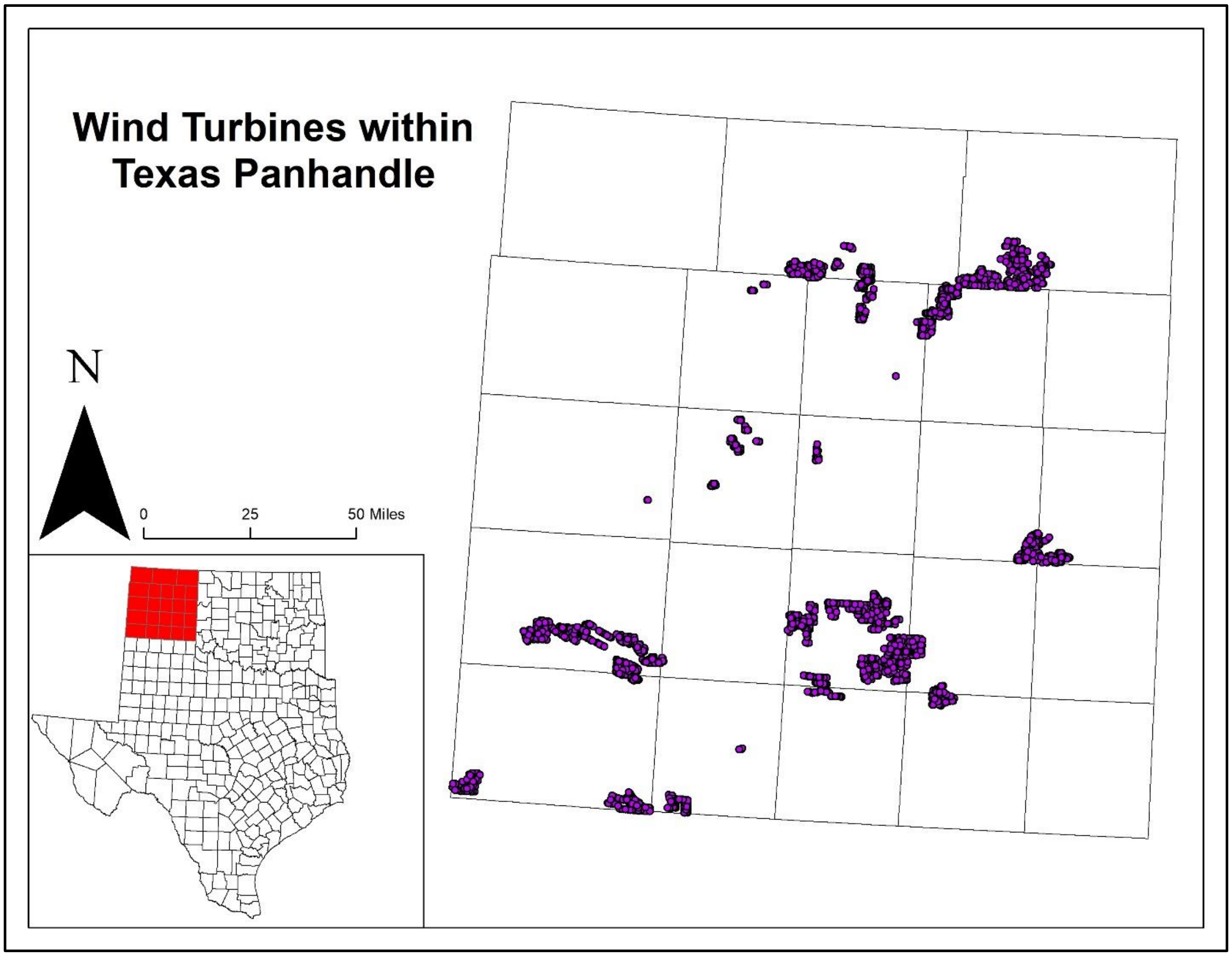

Figure 8. A map showing wind turbines within the Texas Panhandle.

The result from the clip output in Figure 8, provides the user a much more focused study area, to determine the demographic obstructions. In this case, the user sees wind turbines located in multiple Texas Panhandle counties. While the Texas Panhandle may be mostly farm or crop land, there are major highways that run through there as well as the city of Amarillo which has large population. This may provide some useful information or more of a local level compared to the United States as a whole.

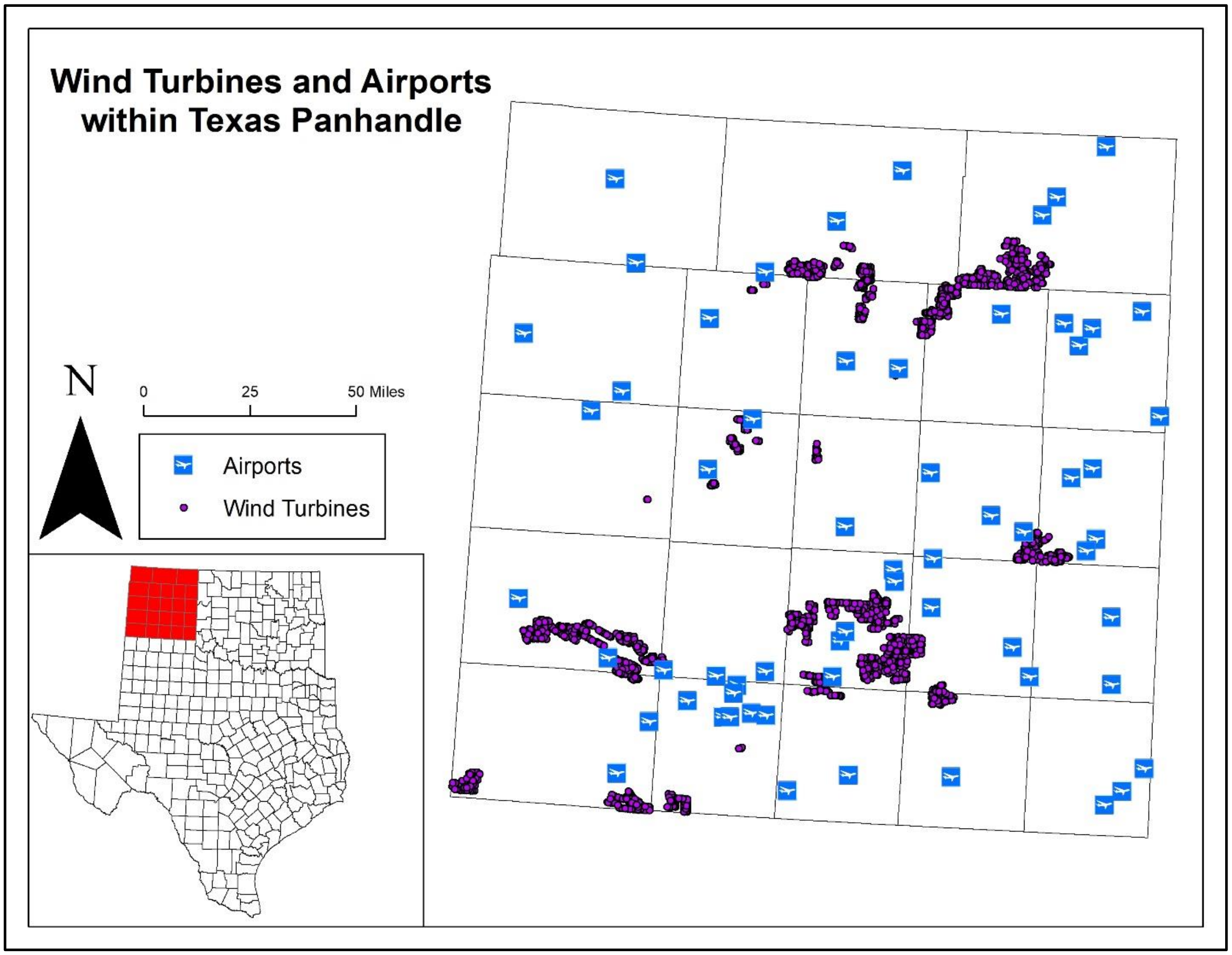

Figure 9. A map showing wind turbines and airports within the Texas Panhandle.

The program allows the user to go a little further by selecting and clipping the wind turbine feature layer along with the airport feature layer viewing them both at the local level. The result from the output as seen in Figure 9, indicates there are many wind turbines and airports in such a localized area. The user should take note of the number of airports surrounding the clusters of wind turbines. Additionally, the pattern in the result should guide the workflow into understanding the proximity at which airports are within a seven-mile radius of these wind turbines.

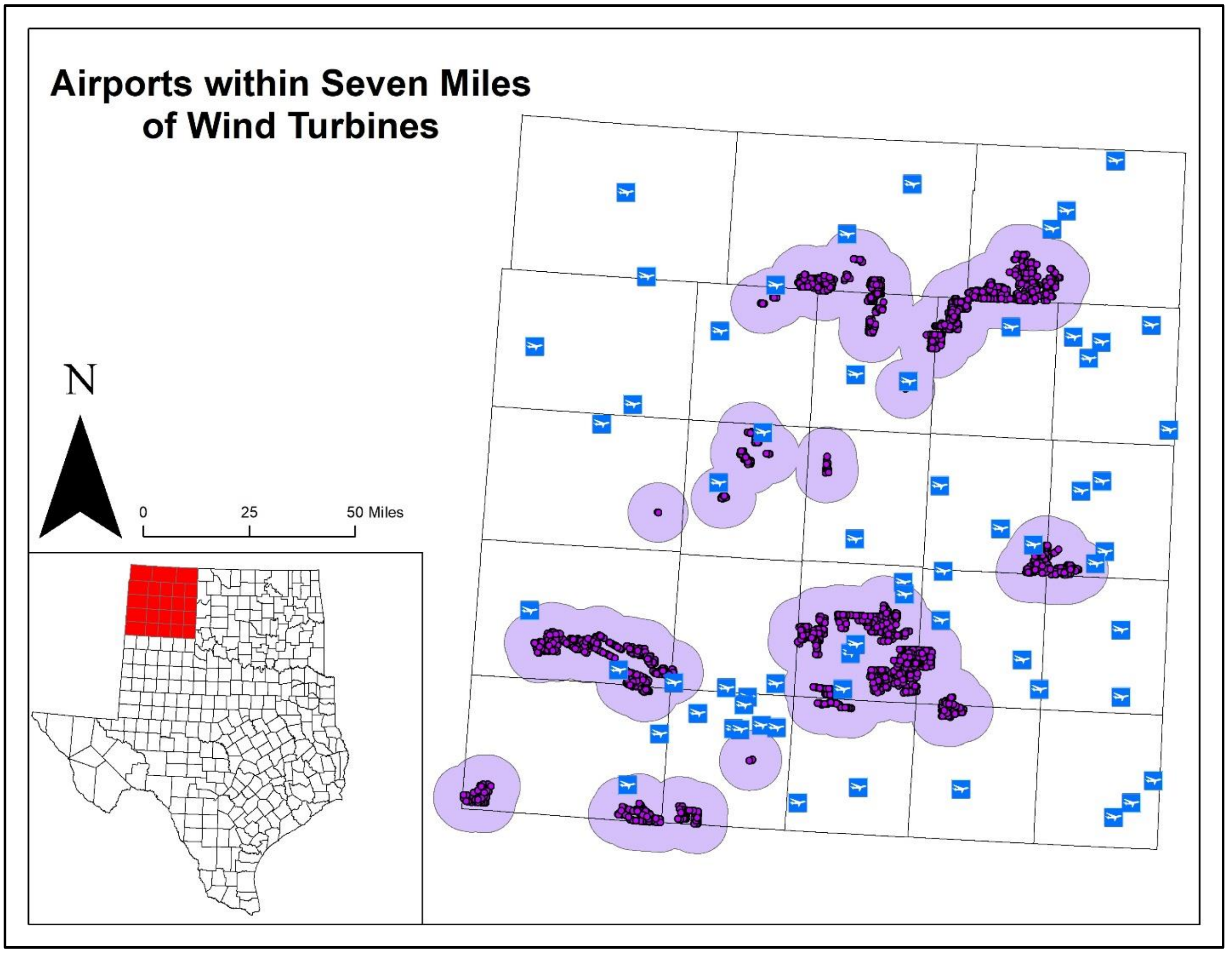

Figure 10. A map showing seven-mile buffers around wind turbines in the Texas Panhandle.

As the program transitions from clipping and selecting, one of the last functions is to create a seven-mile buffer around the wind turbines in the Texas Panhandle. As a result, the user can see that there are not very many airports located within in this seven-mile buffer. However, there are a few, which leads to an interesting analysis and assumption about land suitability at the local level.

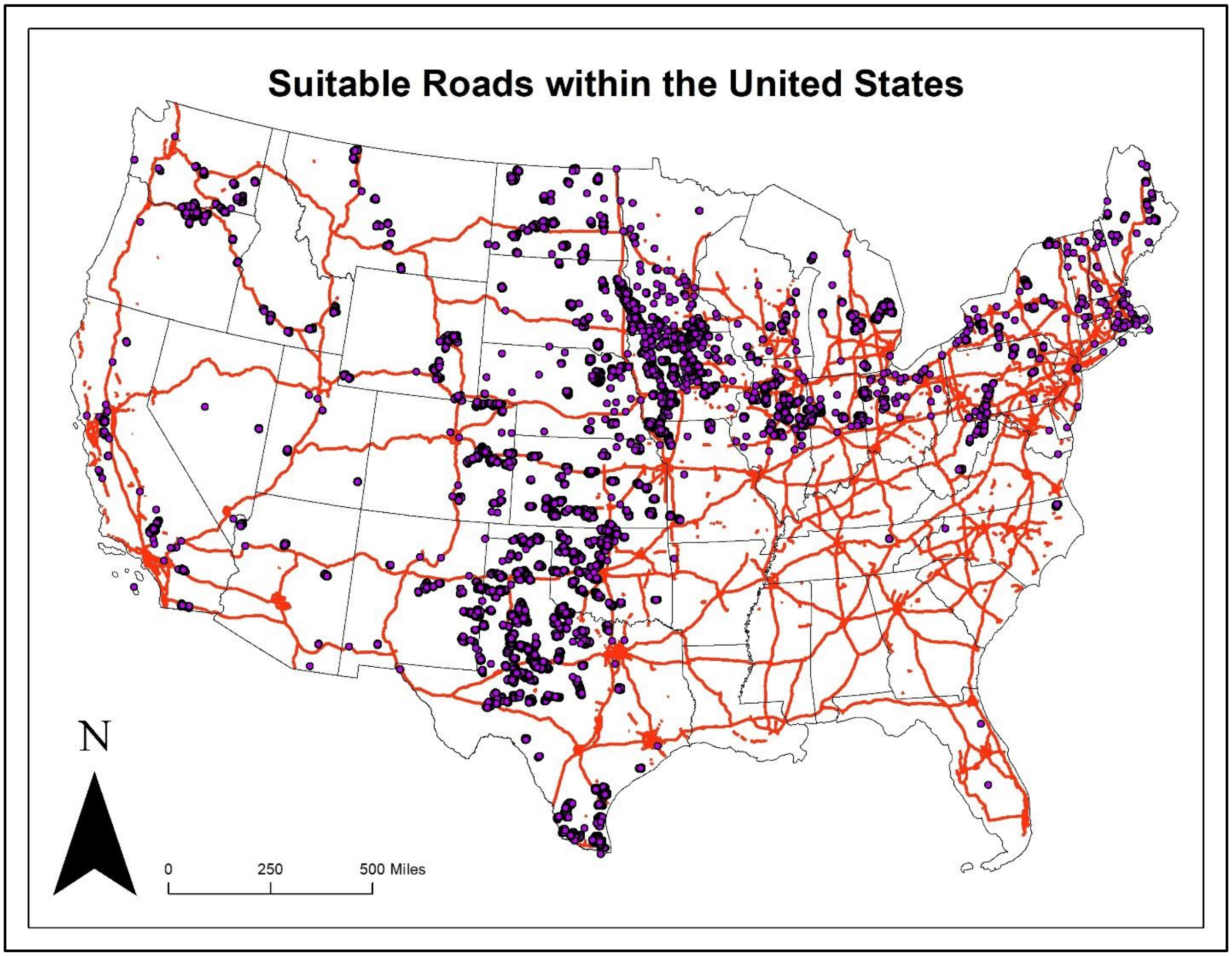

Figure 11. A map showing wind turbines and suitable road within the contiguous United States.

In addition to the last buffer function, the program ends with performing a clip of suitable roads within the contiguous United States. Within some of the scientific literature, suggestions about major travel corridors are considered when deciding on suitable location of wind turbine placement. The result of the output in Figure 11, illustrates an intriguing pattern. The user can see that there are hardly any wind turbines in the deep south, mostly due to the amount of vegetation. This suitable road output would give the user an idea of why most of the wind turbines are located a certain distance away from major corridors.

Discussion and Conclusion:

In conclusion, this paper used a GIS framework to analyze land suitability for wind turbines based off the impact certain factors such as environmental, ecological, cultural, human settlement, and physical infrastructure had on wind turbine placement. More specifically differences in wind speed; distances from road network, urban areas, and differences in the topography of the land could prove to be the primary factors in determining land suitability for wind turbines across the United States. Perhaps the most interesting results were found in the density analysis. The point density of both the wind turbine and airport feature layers illustrated patterns that could possibly lead the user to assume that the current placement of wind turbines across the United States may conflict with some of the various obstructions decision makers and engineers face when determining the development and placement of new locations. Additionally, the buffer result suggested that several airports could pose problems for new development within the Texas Panhandle. However, on the contrary, the wind turbine placement in the Texas Panhandle via analysis provides some useful information as to why they map place more turbines in that region so long as certain measures are met.

This study took a GIS and programming approach to analyze various energy and geographic datasets. As a result, this study provided the user of this geoprocessing program the ability to see the various patterns in determining wind turbine placement and provide some useful information for planners and engineers to aid in decision making. For those who want to research further and continue with the project, I may suggest adding a little more detail at the local level such as road networks and local demographic information.

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