Wind Turbines in Texas: Locational Compromises in Energy Need and Ideal Building Sites

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As long as the Sun's rays continue to hit the Earth, wind will always be a plentiful, renewable, and sustainable resource. Wind power is an increasingly popular clean energy source that has grown globally by a factor of 98 in the past two decades (IRENA). In the United States, Texas is the top producing state for wind energy with its abundant space for wind farm projects and ideal wind conditions (Hegar). The location in which these wind farm projects are built are motivated by a plethora of factors, and this study will address the colocations, correlations, and potential causations for a few: elevation, wind speed, and population density.

Wind turbines are easily integrated in remote and rural areas, but a goal for large-scale wind turbine projects is to provide energy to highly populated areas that need a lot of energy. Also, transporting energy is costly, so compromises must be made in the locations of wind turbines to ensure that it both has potential to optimally power homes while also being in an area with room to build (DOE). Additionally, the same wind turbine farm will produce more energy if the wind speeds in a given location are higher. Although a complex relationship, wind speeds at a fixed height from surface generally increase with more mountainous areas and higher elevations; however, these areas sometimes present difficulties in constructing wind power projects with their rugged terrain (weather.gov). These different complexities lead to needed compromises in wind turbine locations – investigating what compromises already have been made can be valuable for future opportunities in wind turbine placement to optimize power for the future.

The United States Wind Turbine Database provides updated information on wind turbines in the US and complies information from public and private sources to provide information like location, year built, energy capacity, and other technical data for each recorded turbine (USWTDB). For the state of Texas, it is relevant first to study the currently built wind turbines in isolation to better contextualize the trends that already exist. Understanding the developments of wind turbines in Texas over time can give insight to future ambitions and hopes in wind projects.

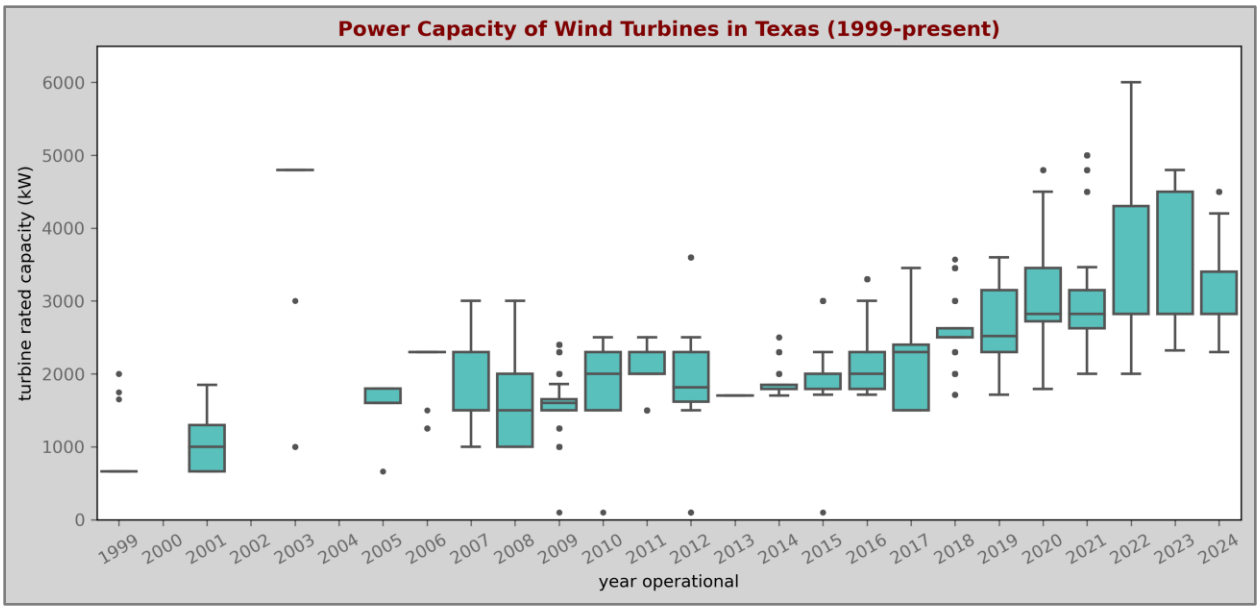

Figure 1: Distributions for power capacities of wind turbines built in Texas, aggregated by year built to depict developments from 1999 to present. Note the year 2024 is incomplete, as the latest data release was on 11/20/24.

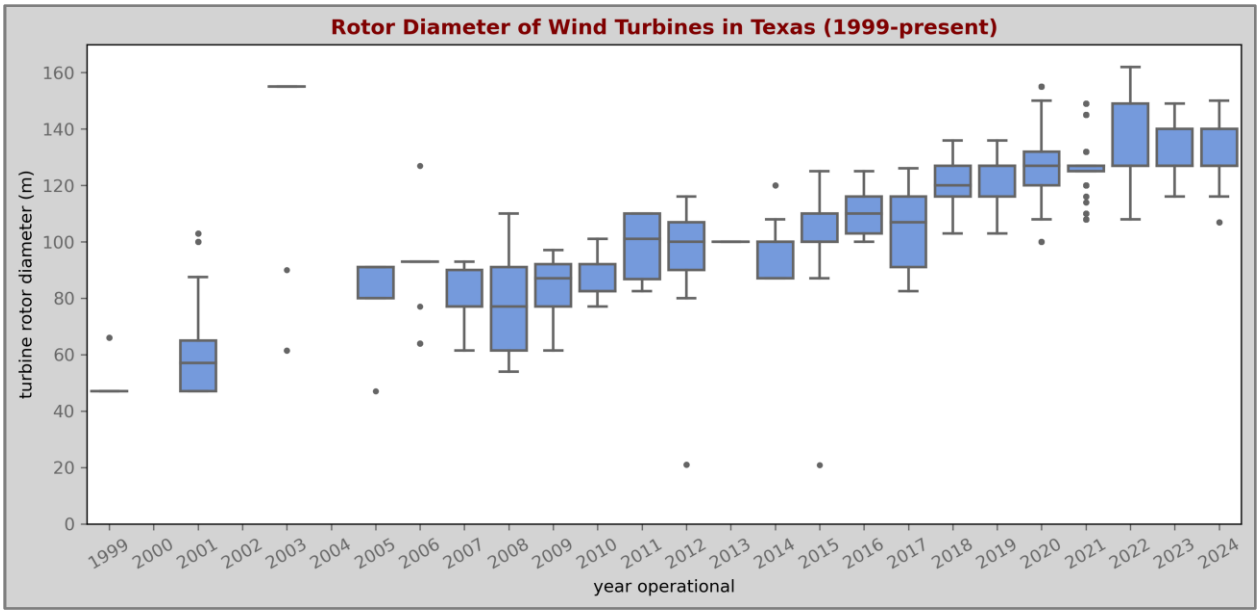

Figure 2: Distributions for turbine rotor diameter of wind turbines built in Texas, aggregated by year built to depict developments from 1999 to present. Note the year 2024 is incomplete, as the latest data release was on 11/20/24.

Figure 1 depicts the distributions of wind turbine rated power capacities for all turbines built in Texas for a given year, and **Figure 2** shows a similar plot but with distributions in turbine rotor diameters. Both plots show a clear increase from 1999 to present day, which indicates that wind turbines have been getting bigger with higher power capacity. A larger rotor diameter means more area for the kinetic energy of wind to convert into rotational then electrical energy, so it is consistent that a larger wind turbine has a higher rater power capacity (IRENA). Recent years, especially after 2020, show little change in both power capacity and turbine size; this may be due to larger wind turbines being unsustainable in cost.

With this important time context in trends for wind turbines in Texas, it becomes especially useful to investigate how the distributions of built turbines correspond to elevation, wind speed, and population density. To make comparative analyses, it is convenient to choose counties as an aggregate to study. Population density for Texas counties is readily available with 2020 census data, and average elevation is similarly accessible online (texascounties.net). Obtaining average wind speeds for Texas counties was a bit more involved: GeoTIFF images, with georeferenced pixels, are available for Texas counties at different fixed heights above surface level at 2x2km pixel resolution (NREL). Using this data, along with a GeoJSON of Texas counties makes it possible to determine statistics for each county derived from the GeoTIFF using a cartography software like QGIS (QGIS). Based off exploratory analysis, most Texas wind turbines have an average hub height around 80 meters, so average wind speeds were calculated for each county at 80 meters above surface. With these steps, elevation, wind speed, and population density can now be studied at the county level with wind turbines.

Figure 3 shows the distribution of average elevation and average wind speeds at 80 meters above surface for all Texas counties. There is an apparent moderate correlation between the factors, where a higher elevation generally means a higher wind speed. It is clear in both the scatter plot

and histogram that wind turbines are built in counties with higher wind speeds; however, there is no clear correlation that points to more turbines being built in the highest wind speed counties. Wind turbines are built at all elevations, starting at even the lowest areas – there are a few counties with exceptionally high elevations, but these counties have relatively low wind speeds.

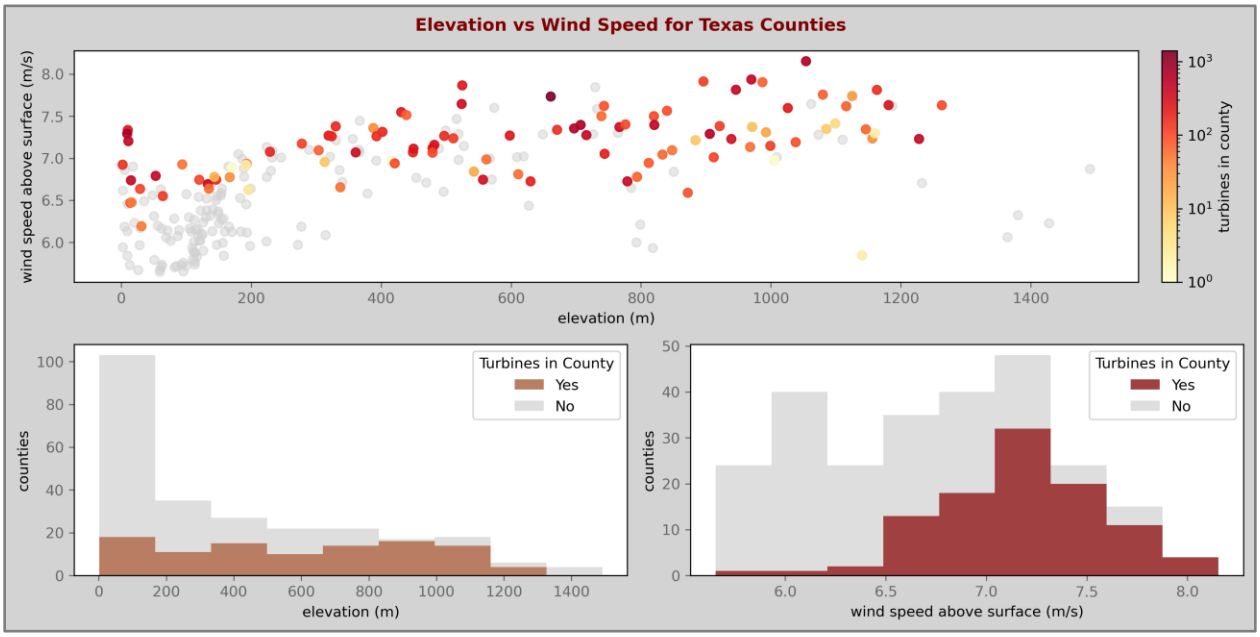

Figure 3: Distribution of average elevation and average wind speeds at 80m above surface for Texas counties. Counties with turbines are highlighted, encoding information on the number of turbines in that county. Also shown are distributions of elevation and wind speeds for Texas counties, with stacked histograms of counties with turbines compared to counties with no turbines.

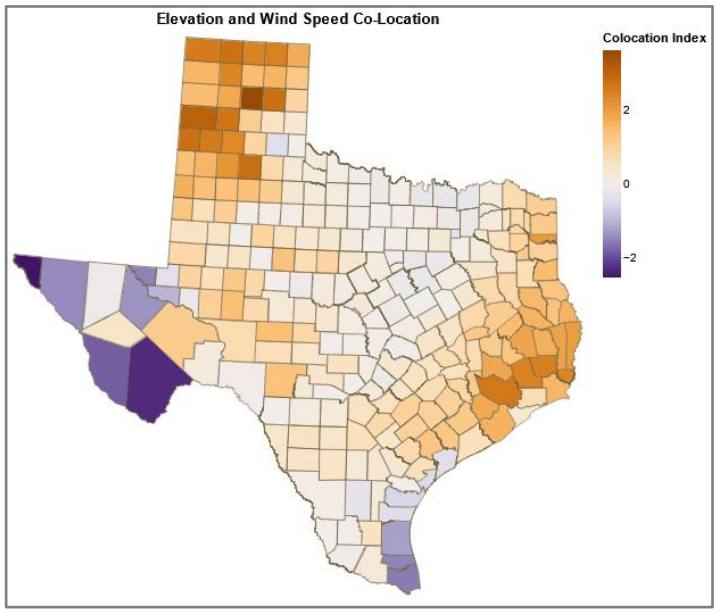

Figure 4: Colocation between average elevation and average wind speed for Texas counties.

To explore the complex relationship between average elevation and average wind speed at 80 meters above surface for Texas counties, a colocation analysis was done where the variables were standardized to produce a colocation index. A positive colocation index indicates that the variables are correlated, but it can be valuable to study places where this index is negative which indicates discrepancies. In Figure 4, the Western tip of Texas is one of these areas, and counties are characteristically very high in elevation but relatively average to low in wind speeds. And the southern Gulf Coast counties are at a

low elevation being near the sea, but have fairly high wind speeds compared to nearby counties. This context is important, as a higher wind speed does not necessarily mean a higher elevation.

Figure 5 plots each wind turbine over maps encoded with information on population density and average wind speeds. While low population areas are optimal to build in, wind turbines need to provide power to higher population areas. Wind turbines avoid the highest populated areas, with a couple exceptions in southern Texas. Figure 5 also demonstrates that wind turbines are built in areas with high wind speeds, which could explain the effort to build turbines in populated areas in southern Texas. Areas with high wind speeds but no nearby population hubs, like lower-central Texas and the corners of the panhandle, seem to be avoided completely by wind power projects. In general, wind turbines are built in areas with high wind speeds - they do not sit on a densely populated areas but are not too far away from any population hubs. Based on this rule, an example of a potential building site is indicated by an arrow. Similar choices can be made for new wind projects given this comprehensive analysis.

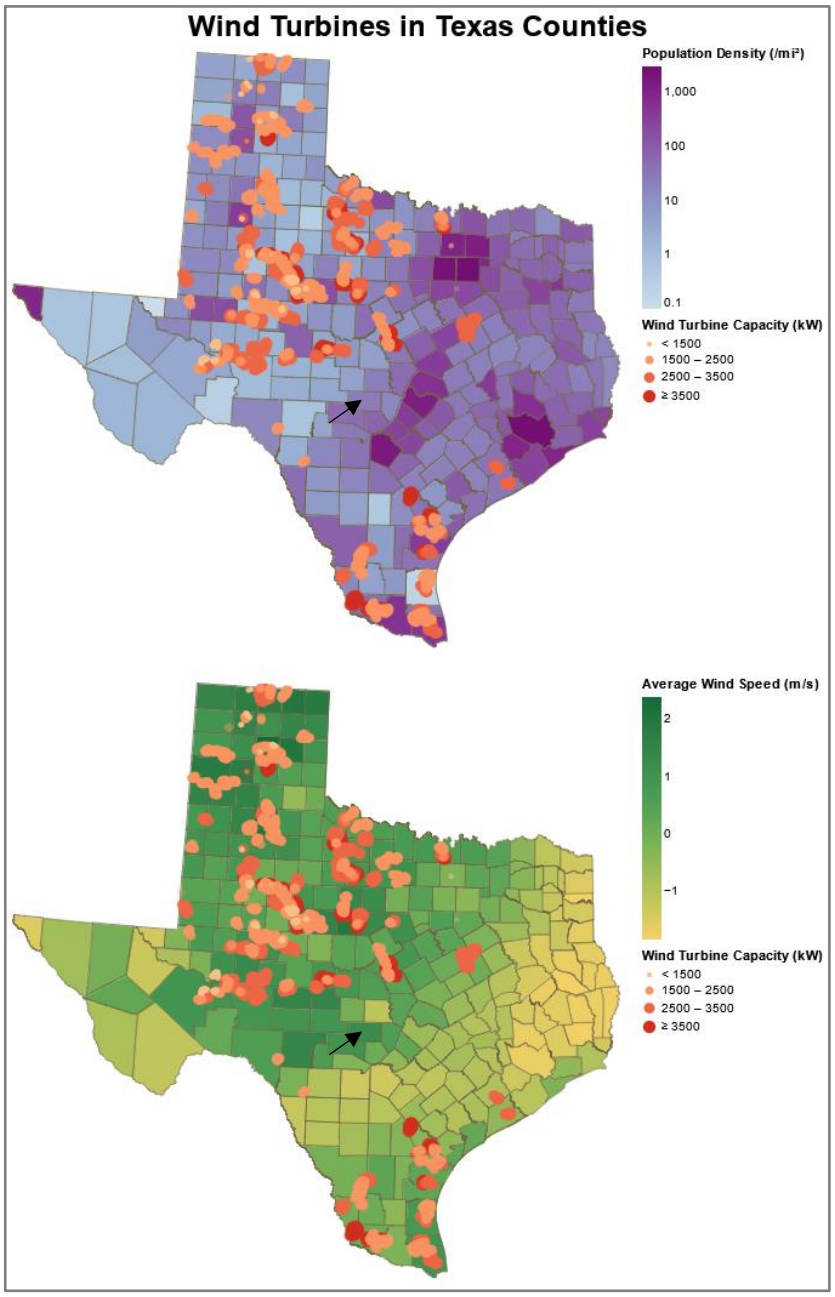

Figure 5: Wind turbines plotted over choropleth maps of Texas counties, encoding population density and average wind speed at 80m above the surface. The locations of wind turbines are also encoded to show their rated power capacity.

Works Cited
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