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Process Book: United States Wind Turbine Visualization

Overview and Motivation:

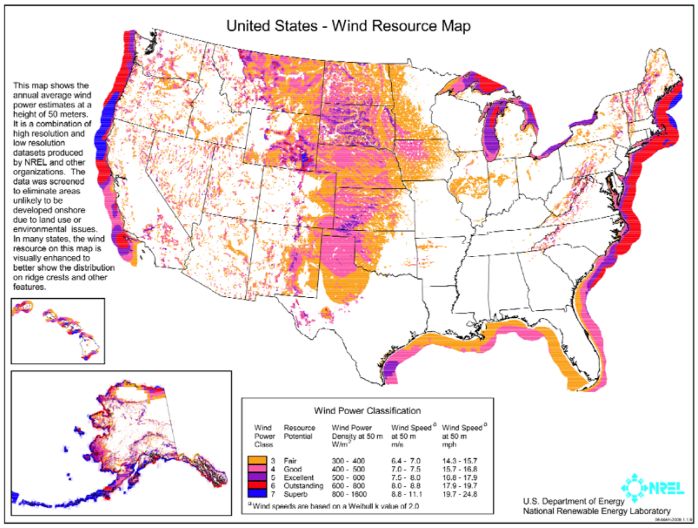
Wind energy stands out as a significant contributor towards sustainable energy development. As the United States tries to reduce the use of fossil fuels to make energy and instead use other much eco-friendly methods, wind turbines become of great importance across the landscape. Wind turbines play an essential role in converting wind energy into electric power. Their mode of operation is based on propeller rotation, which powers an internal generator, thereby producing electricity. In fact, wind turbines also offer lucrative employment opportunities that contribute to economic growth. Our motivation stems from the increased importance of wind turbines and the necessity to understand the particular distribution of them. Our project's aim is to provide a clear view of wind turbines across the United States' landscape. The visualizations provide insight into wind turbine distribution using factors such as location, manufacturer, number of turbines, and turbine capacity.

Related Work:

We drew inspiration towards this specific project from various sources and discussions. First, we reviewed a few datasets and papers, including papers on renewable energy adoption and wind turbines. One of the papers stated, "The risk of human-induced climate change and the volatility of world oil markets make non-fossil fuel options important" (De Vries et al., 2007). This shows the significance of finding other energy options, including wind, solar-PV, and biomass (WSB).

Another paper we came across through is "Titled "Wind power development in the United States: Experience and prospects" (Hartley, Peter R. , 2010). This paper gave us the idea of how important it is to visualize this aspect of energy to develop cost-effective and efficient energy supplies in the future.

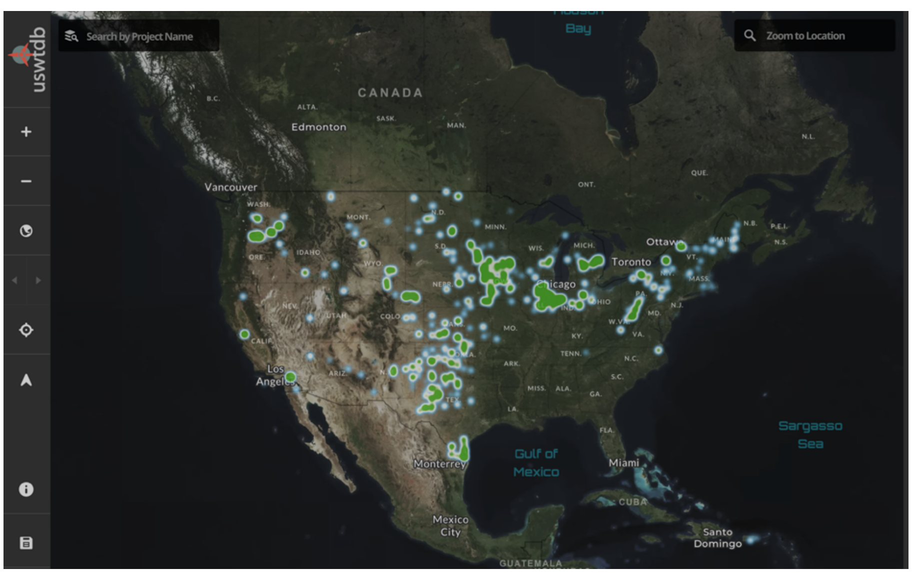
Figure 2: United States wind resources



" (Hartley, Peter R. , 2010)

The image above shows the wind resources in the United States. Using this visualization, one can predict where better resources are located, how expensive it can be to develop a wind farm in a certain location and etc.

From here we went on to look at the United States Wind Turbine Database. Where we found very useful data. Specifically, a geographical visualization instantly came into consideration. In fact, we also found a visualization using the same, United States Wind Turbine dataset, giving us more inspiration and ideas.



Picture of visualization using same dataset as us. (Hoen, B.D. et.al, 2018)

Other relevant work we looked into includes:

1.) Title: "Analyzing the factors influencing the wind energy adoption in Bangladesh: A pathway to sustainability for emerging economies".
Link: https://www.sciencedirect.com/science/article/pii/S2211467X23002158

2.) Title: "Renewable energy policies and cross-border investment: Evidence from M&A in solar and wind energy".
Link: https://www.oecd-ilibrary.org/docserver/5jxv9f3r9623-en.pdf?expires=1701535016&id=id&accname=guest&checksum=54A85E854FF324390D281EC371C236FA

Questions:

The following questions are answered in our visualization:

1.) Where are wind turbines generally located in the USA?

- The answer to this question can be important since it can be used for spatial distribution analysis of wind turbines across the United States of America. This will also assist in understanding the geographical patterns of where these wind turbines are installed. This was one of the first questions we decided to focus on based on our aim.

2.) Which manufacturers build wind turbines and where are they installed?

- The significance behind this question could be for market analysis. For example, to understand the trend in wind energy industry. It can also help us understand the location where a certain manufacturer has more wind turbines built compared to another location.
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3.) Which capacity range of turbines are the highest in number?

- The answer to this question can be very useful for one to determine the most optimized resource. It let user identify the type of turbines that are highest in demands. It can also be used to analyze what needs to be changed or innovated based on a research perspective.

4.) What are the number of new turbines per year?

- This question addresses the industry growth as time passes. It assesses how significant is the growth of the wind turbines industry over the period of time. It also gives a general idea to plan for the integration of new wind energy capacities.

Other than the general questions stated above, there are many other much specific questions that can be answered based on the filter present. For example, we can identify the number of wind turbines and the capacity distribution by one specific manufacturer. Overall, as we progressed with the project and delved more into the dataset, the more the questions developed. The first two questions were instantly identified.

Data:

The source of the dataset is from the United States Wind Turbine database. The creation of this dataset was funded by the following: U.S. Department of Energy (DOE) Wind Energy Technologies Office (WETO) via the Lawrence Berkeley National Laboratory (LBNL) Electricity Markets and Policy Group, the U.S. Geological Survey (USGS) Energy Resources Program, and the American Clean Power Association (ACP). The dataset was compiled by FAA, US Geological Survey, and other organizations. Each row in the dataset appears to represent individual turbines. Among the various columns, specific ones like case_id, faa_ors, faa_asn, usgs_pr_id, and eia_id act as unique identifiers. The dataset also provides geographical data such as state, county, FIPS code, and precise coordinates (longitude and latitude). Turbine specifications included range from manufacturer, model, capacity, hub height, rotor diameter, rotor swept area, to total height.

The dataset was downloaded in its raw format. Once we have the dataset, first we decided to analyze it and understand the significant measures. Next, we cleaned the data by addressing the NULL values and making sure that all the units of the column are consistent. Since the first Idea we had was to create a map, we ensured that we have significant geographical data.

Exploratory Data Analysis:

First of all, we used a geographical map to view the distribution of the wind turbines across the United States. The wind turbines represented a dot on the map and the color intensity of each state representing the number of turbines specifically in that state. Next, we thought of a line graph that will represent the number of turbines built over time. A major insight that was gained from the mentioned visualizations was the spatial patterns. It indicated areas with higher wind energy infrastructure is present and also gave a brief identification of growth along with fluctuation of wind turbines over time.

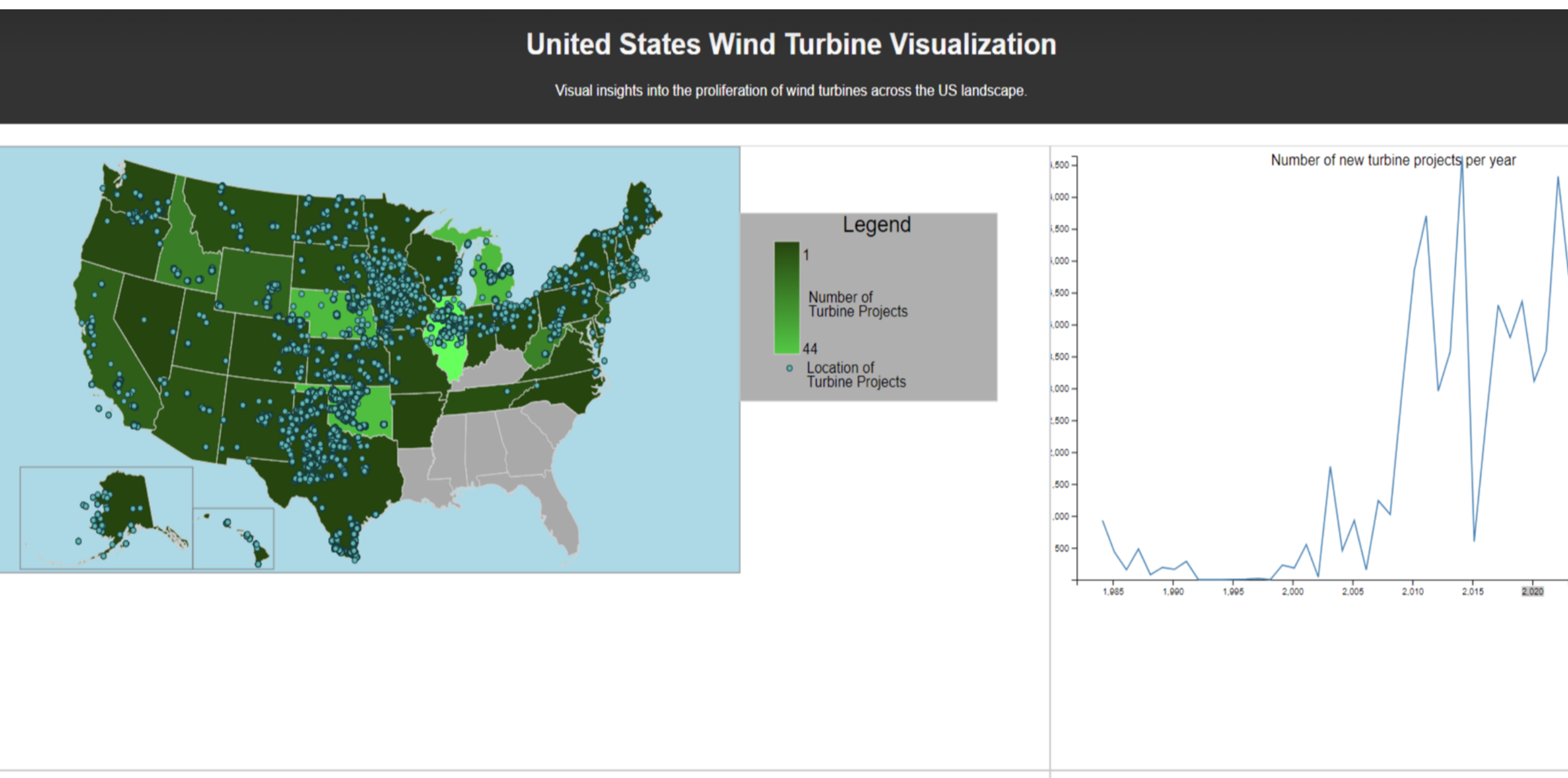
This visualization gave us ideas that would influence our eventual design. For example, we identified that there are many other variables that can explain essential trends of the wind turbines. By looking at the present variables, we identified that a bar chart representing the capacity distribution of the wind turbines could be a useful visualization and a pie chart to represent the distribution of the manufacturers of these wind turbines. The initial design also influenced our ideas of adding filters such as focusing a specific state or a specific manufacturer.

Design Evolution:

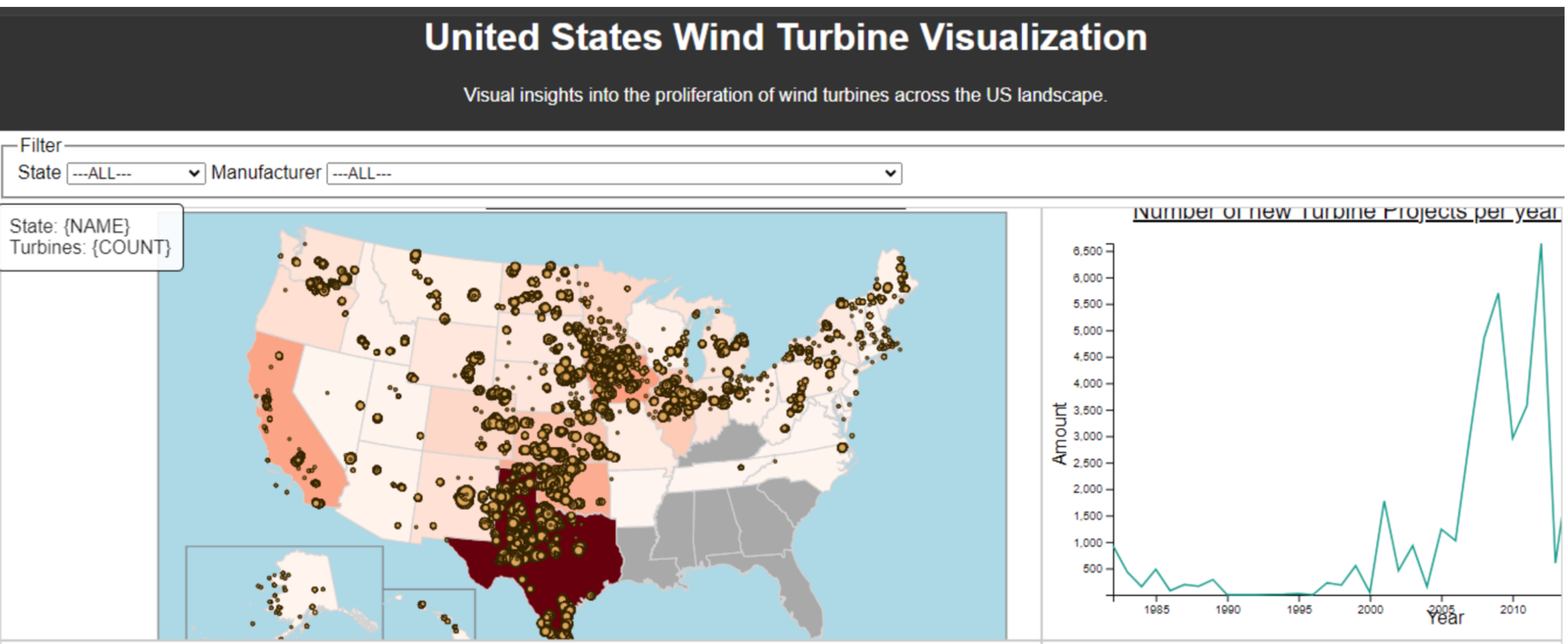
As mentioned before, the first visualization we thought of was a geographical map visualization. Based on the data, we decided to do a point map rather than any other type (heat map etc.). A point map distinctly points out each wind turbine on a specific state. Initially, we drew the following idea on a computer:

Even though we had county information of each turbine, we decided to use the state information since the graph get very crowded and confusing with specific counties.

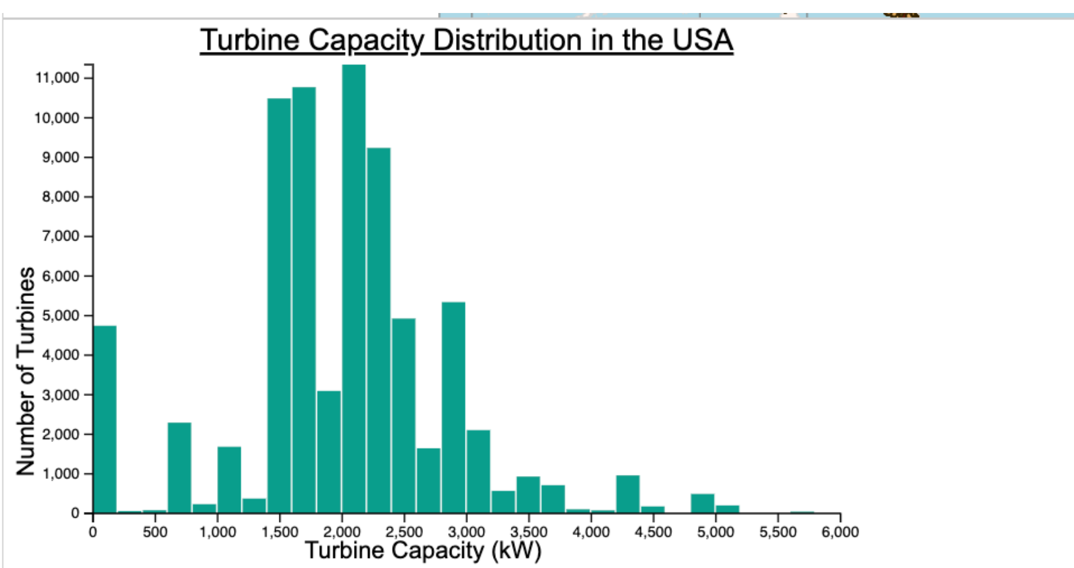
Our first attempt on D3.js on the geographical map is the following:



The graph on the right shows a line graph that displays the number of wind turbines over time. As learned in class, a line graph can clearly show the trends of something over time. On the other hand, the map that is on the left has points representing the wind turbines along with color shades of green representing overall number of turbines in a particular state. We had a group discussion based on the initial visualizations and decided that the color scheme was not effectively portraying the overall number of turbines per state. After this, we change the color scheme to something that is more easily distinguished.

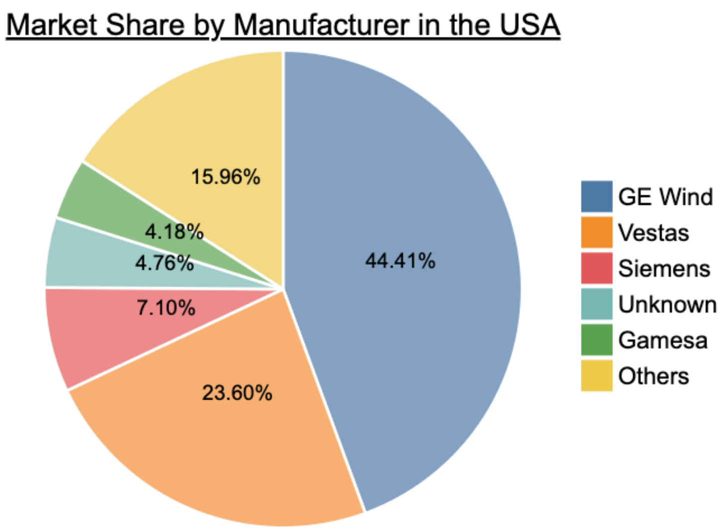


The following is a bar chart that was added to our D3.js visualization showing the capacity range of wind turbines that are manufactured in the United States. A bar chart was used since there were distinct numbers for capacity range of wind turbines.

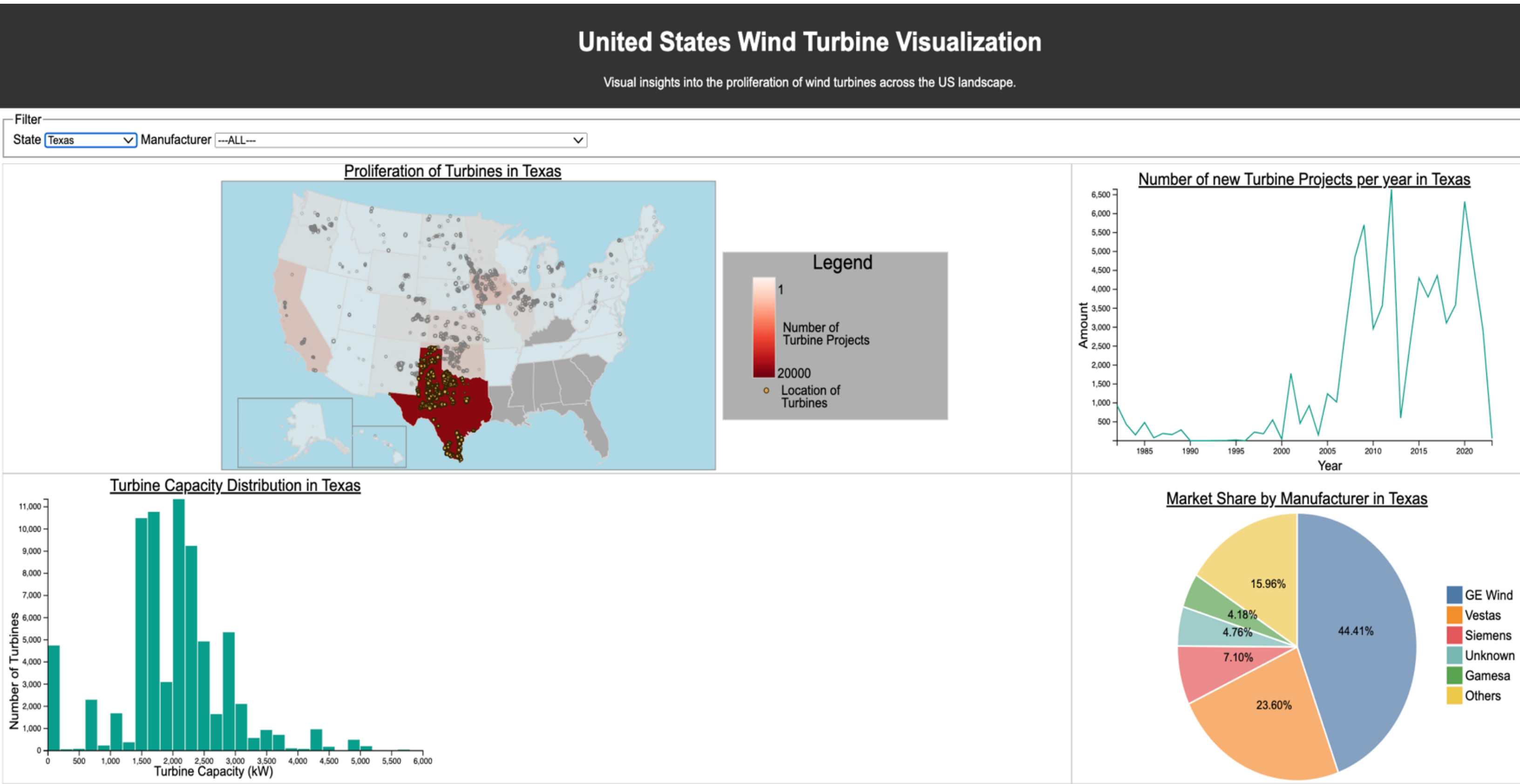


Lastly, we decided to add a pie chart representing the market share by manufacturer in the USA.

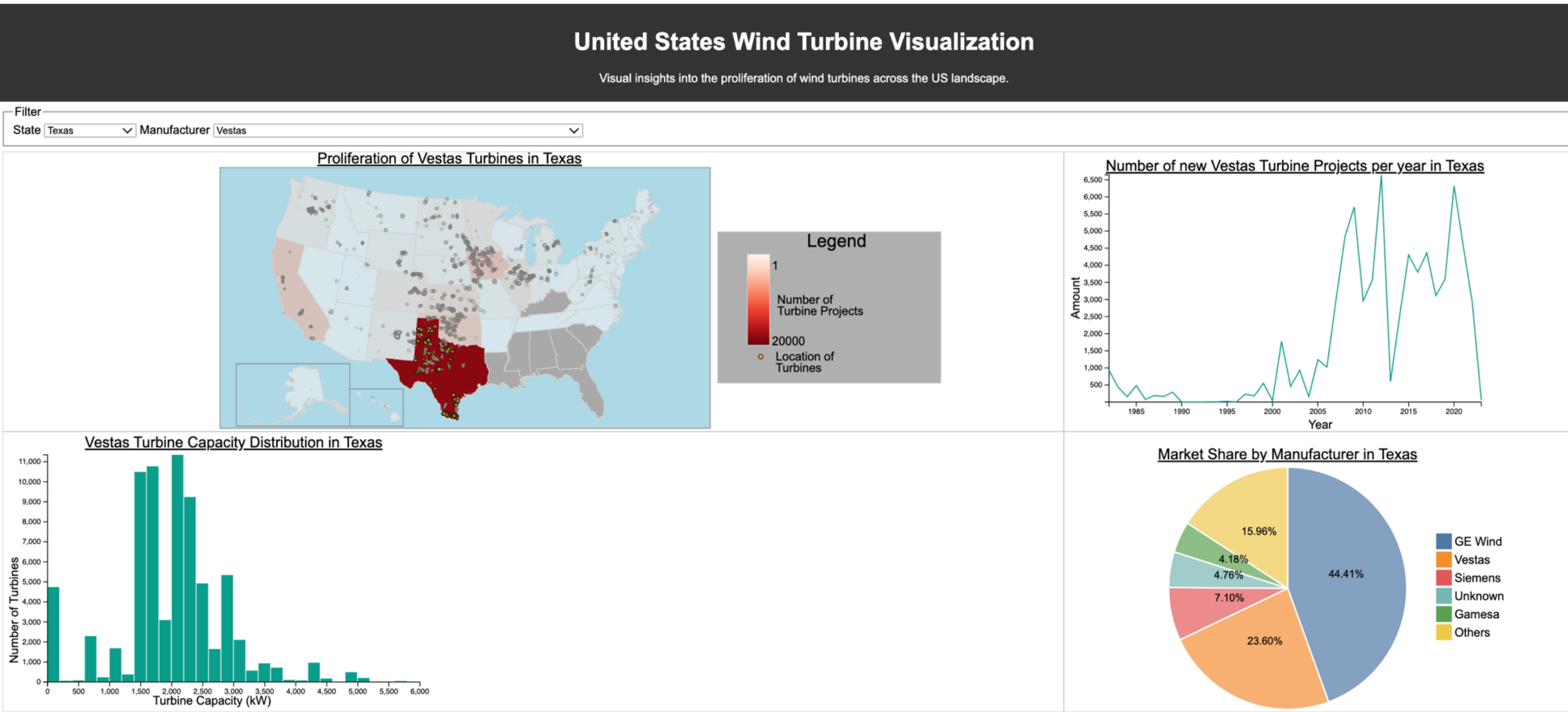
Implementation:



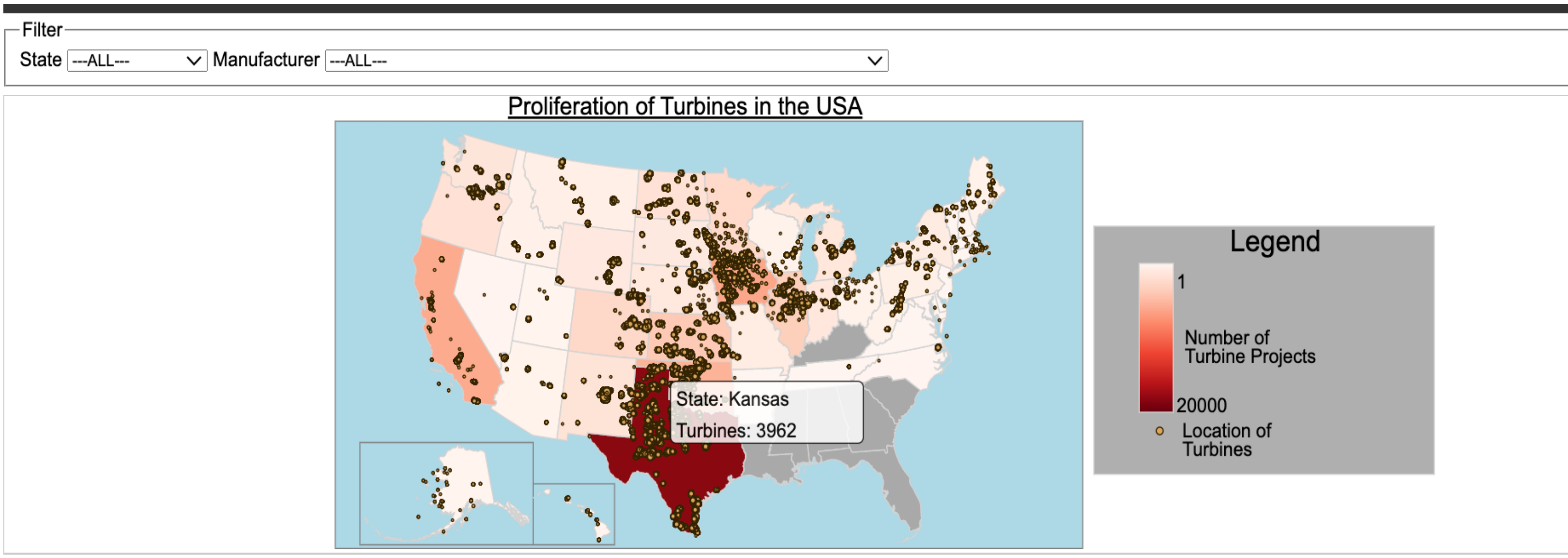
The visualization had had interactive features that allows user to explore the wind turbine data dynamically. The filters enable the user to see all visualizations based on a specific state. As shown below, all the visualizations are based on the state filter of Texas:



The other filter displays all the visualization based on a certain manufacturer. For example, the following image shows all the visualization based on only Vestas manufacturer:



Lastly, once hovering above the map, one can see information about number of turbines and name of state as seen below:



Evaluation:

The visualization gave an insight to spatial and technical aspects of the data. All our four questions can be answered very thoroughly using our visualization. The highest number of wind turbines are generally located in Texas with 18552 turbines present. Which manufacturers build wind turbines and where are they installed can be identified. The capacity with highest number of turbines is approximately 22000kW. In fact, we can see the trend of number of turbines over time. The interactive features enhance user experience and engagement and allow one to explore much more details of the data. For example, it can answer the question "How many turbines have been built over time in only Texas".

The visualization worked effectively and one way we believe we can improve on this visualization is by adding more filter. Overall, as we learned in class, the importance of visualization can be clearly seen in the project. The analysis and information we get to see from the visualization would never be possible to see from the raw dataset.

References:

De Vries, Bert JM, Detlef P. Van Vuuren, and Monique M. Hoogwijk. "Renewable energy sources: Their global potential for the first-half of the 21st century at a global level: An integrated approach." *Energy policy* 35.4 (2007): 2590-2610.

Hartley, Peter R. "Wind power in the United States: prospects and consequences." (2010).

Hoen, B.D., Diffendorfer, J.E., Rand, J.T., Kramer, L.A., Garrity, C.P., and Hunt, H.E., 2018, United States Wind Turbine Database (ver. 6.1, November 2023): U.S. Geological Survey, American Clean Power Association, and Lawrence Berkeley National Laboratory data release, https://doi.org/10.5066/F7TX3DN0.