Exploratory Data Analysis: Time Series Lab

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CEE 322 - Lab 2

Introduction

The use of renewable energy resources for utility electricity generation is becoming increasingly popular around the world. When considering adding more renewable sources to a generation portfolio, utilities must consider the feasibility and potential benefits of a renewable source in specific locations. Two of the main sources of renewable energy are wind and solar energy. Using photovoltaics or wind turbines can provide clean energy, but the output of these energy sources rely heavily on local weather conditions. Solar energy can only be captured during daylight hours and it performs better in locations with higher solar radiation. Wind turbines can only operate in locations with predictable winds and are limited by a minimum required wind speed to turn the turbine and a maximum wind speed at which it is safe to operate.

In this report, we will examine weather conditions in Deer Lodge, Montana and Ashton, Idaho. We will analyze wind direction, peak wind gust, wind speed, and solar radiation over a one year period in 2014 in order to determine feasibility of using solar and/or wind generation.

Dataset

For this analysis, we will use weather data over the year 2014 for each location. Weather data is obtained from the United States Bureau of Reclamation. Data was indexed in sequential order with a time and date being two seperate variables. From this database, we will explore the following four variables:

- Wind Direction (WD) defined as the hourly mean of the wind vector [degrees azimuth]
- Peak Wind Gust (WG) defined as a 15 minute long gust [mph]
- Wind Speed (WS) defined as an hourly average [mph]
- Solar Radiation (SI) defined by a 15 minute block per hour [watts / m2]

In order to utilize a more familiar unit for SI, the SI data was converted from langleys / hour to watts / m2 using the conversion factor of 1 langley / hour = 11.63 watts / m2. No outliers were removed.

While the dataset is sufficient for this initial analysis, the period between measurements was one hour, wherein there could be large fluctuations in wind and solar behavior. For a more thorough analysis, data could be collected at more frequent intervals to gain a deeper understanding of the conditions at each location.

Analysis

To begin the analysis, we explored the overall scale of the solar and wind at each location. For solar, we determined the annual solar radiation and the average daily solar radiation. Deer Lodge received 1,552,723 watts / m2 with a daily average of 4,254 watts / m2 / day. Ashton received 138,615 watts / m2 with a daily average of 379 watts / m2 / day.

While the total solar energy available is important for understanding the amount of solar at each location, it's also important to note the yearly trend- i.e. will solar be able to provide energy throughout the entire year or is it a seasonal energy source. To explore this further, we conducted a seasonal decomposition, shown in Figure 1 (Deer Lodge) and Figure 2 (Ashton), utilizing a sampling frequency of one month (assumed to be 30 days). While both locations have similar trend shapes (higher solar radiation during the summer months), we can see that Deer Lodge is around one order of magnitude higher than Ashton, with Ashton's minimum being around 5 watts / m2 while Deer Lodges' is around 50 watts / m2. Although the radiation is not constant year-round, Deer Lodge can still extract a fair amount of energy from solar while Ashton would receive very little energy during those low radiation months.

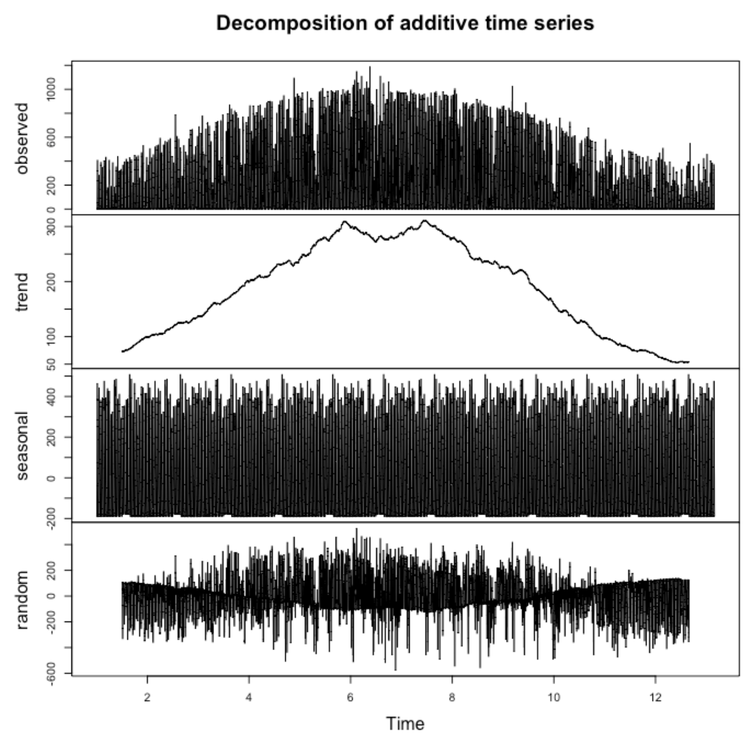

Figure. 1 Deer Lodge seasonal decomposition

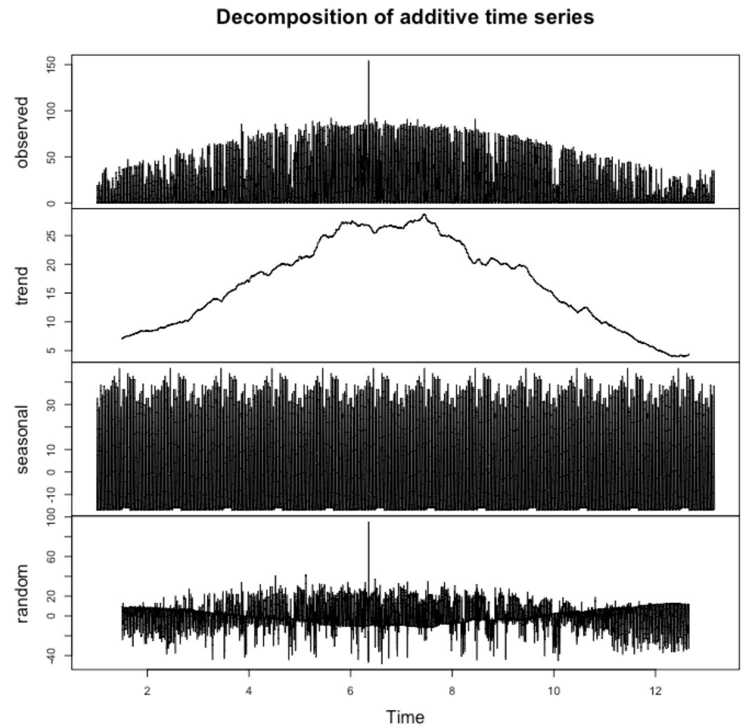

Figure 2. Ashton seasonal decomposition

For wind, we first assessed the average wind speed, which is summarized in Figure 3. For Deer Lodge, the minimum, first quartile, median, mean, third quartile, and max was 0.00, 2.86, 4.88, 6.64, 9.13, and 31.92 mph, respectively. For Asthon, the values were 0.00, 3.72, 5.73, 7.10, 8.83, and 33.69 mph. The results show that Ashton has slightly higher values, which means they can capture more energy from the local wind.

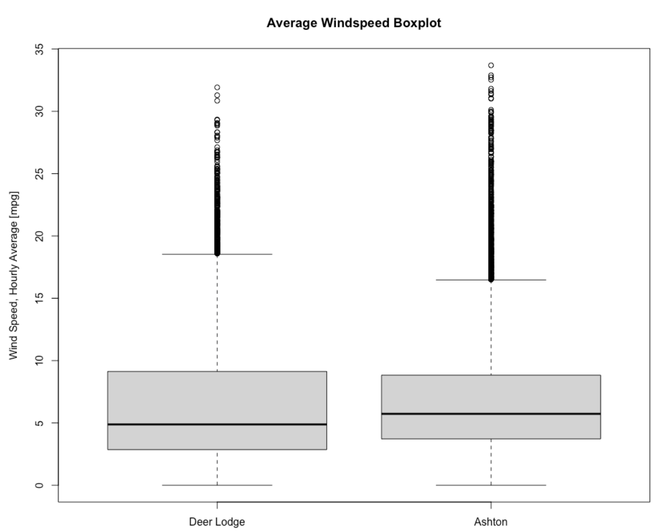

Figure 3. Boxplot of average wind speed at Deer Lodge and Ashton.

After understanding the basic characteristics of the wind speed, we then analyzed the wind gusts, shown in Figure 4. A major concern with wind gusts is the wind gets too strong meaning either the turbines cannot safely operate and need to be stopped or sudden gusts can put strain on the turbine over time. A standard maximum wind speed for turbines is around 55 mph[1]. For both locations, the wind gust data is skewed right with very few instances of the wind gust getting higher than 55 mph in either location, suggesting large gusts are not a major concern for these locations. It should also be noted that most turbines require around 5 mph of wind speed to begin generating, meaning there are many instances at Ashton where the wind may not be generating energy.

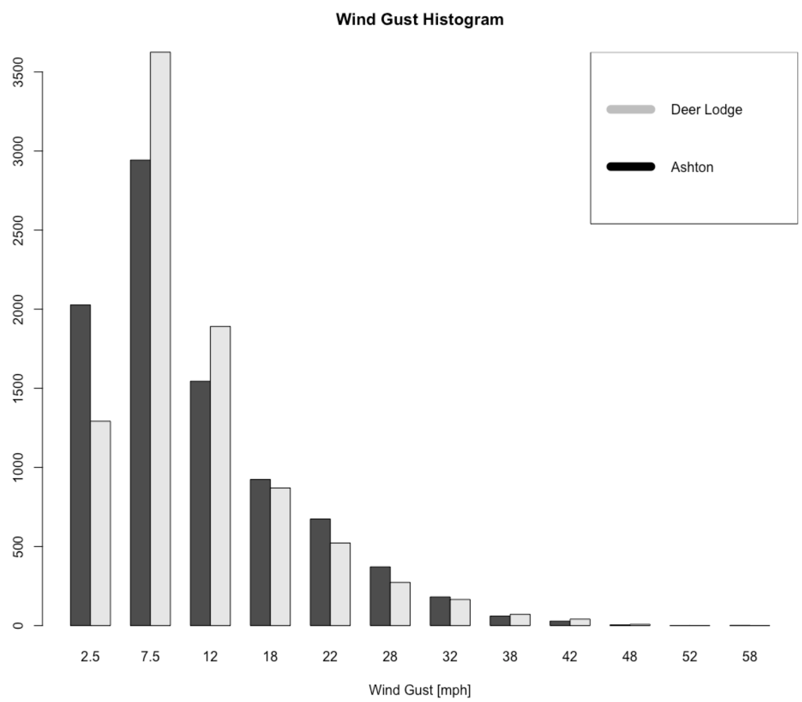

Figure 4. Wind gust histogram for Deer Lodge and Ashton

Another wind consideration is the direction of the wind. While many turbines can rotate to face orthogonal to the wind direction, too much movement or frequent movement can start to wear down the turbines. Figure 5 shows scatterplots for the wind direction. At Deer Lodge the wind direction appears to be spread across the 360 degree options while at Ashton the values appear to be clustered near 90 degrees and 250 degrees. This suggests the wind direction at Ashton is more consistent.

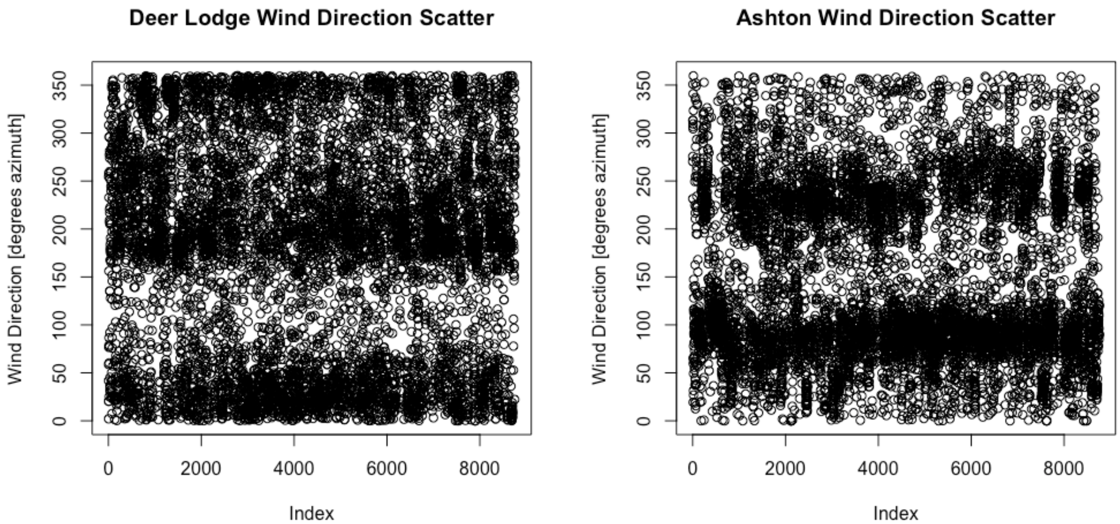

Figure 5. Scatter plots for Deer Lodge and Ashton wind direction

Finally, comparing the cross-correlation of wind direction and wind gusts at the two locations (Figure 6), we see that Ashton has a correlation that is a magnitude higher than that of Deer Lodge, suggesting Ashton may have more predictability.

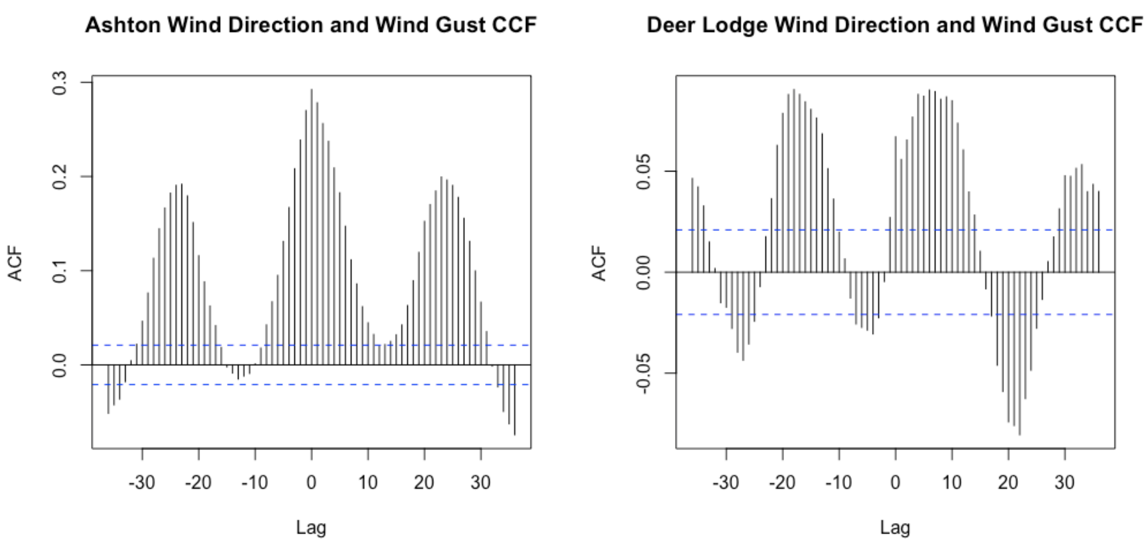

Figure 6. Cross-correlation of wind direction and wind gust at Ashton and Deer Lodge.

Conclusion

Based on the analysis, we suggest that Deer Lodge prioritize solar generation while Ashton prioritize wind generation. The analysis shows Deer Lodge has much more total solar radiation as well as higher levels of solar radiation across seasons. On the other hand, the analysis shows that Ashton has slightly higher mean and median wind speeds, has more consistent wind direction, and wind gust and wind direction is more correlated. Although we believe Deer Lodge should focus on solar, it still has viable wind speeds that are somewhat similar to Ashton. While more consideration should be taken on the predictability and variance in wind direction, wind could still be a reasonable option for Deer Lodge.

In an attempt to pick another location that could utilize solar energy, we decided to analyze Boise, Idaho. We picked this location as a National Renewable Energy Laboratory global solar radiation map[2] suggested that Boise and Deer Lodge would have similar radiation. However upon analyzing, we found that the solar radiation was more closely aligned with the Ashton values, with an annual radiation of 145,064 watts / m2 resulting in a daily average of 397.43 watts / m2 / day. Additionally, solar radiation in Boise followed similar trends (when seasonally decomposed) of having peaks in the summer and lows in the winter. We also analyzed the wind potential at Boise and found that wind speeds were around half that of Deer Lodge or Ashton. While the Boise location had similar cross-correlation values as Ashton, the low wind speeds would make it more difficult to capture wind energy. The analysis of the third location shows that (1) Boise may not be a great location for either solar or wind generation and (2) a deeper understanding of the local climate is necessary to pick potential locations rather than just looking at a solar radiation heat map of the USA.

References

[1] Graff, Frank. “How Much Wind Does a Wind Turbine Need?” *UNC*, https://science.unctv.org/content/how-much-wind-does-wind-turbine-need.

[2] “Solar Resource Data, Tools, and Maps.” *NREL.gov*, https://www.nrel.gov/gis/solar.html.