Wind and Solar Energy Resources Modeling and Analysis

Technical Presentation

By
Mohamed Abuella
The University of North Carolina at Charlotte

August 6th, 2019

Presentation Outline

- **Wind Energy Resources Modeling**
- **Solar Energy Resources Modeling**

Personal Introduction

Mohamed Abuella
https://mohamedabuella.github.io

An electrical engineer by training, traditionally is interested in Mathematical and Computational Analysis, Modeling and Optimization, and who is recently get passionate in Artificial Intelligence and Data-driven Analytics for Energy and Smart Grid applications.

Hobbies and Interests

Making Mediterranean Food and Drink, but also try my own out-of-box recipes;

Stretching, Walking, Running, Driving, Swimming, Diving, ..and hopefully Climbing;

Wondering around and Discovering New Places, ..find it kind of an adventure;

Watching, Reading and Sharing Stuff on Internet, useful & dumb things;

And more often just.. Chilling and Enjoy Doing Nothing!

Wind and Solar Energy Resources Modeling and Analysis

For Different Locations in the U.S.

Four U.S. Locations for Comparison of Renewable Energy Modeling and Analysis

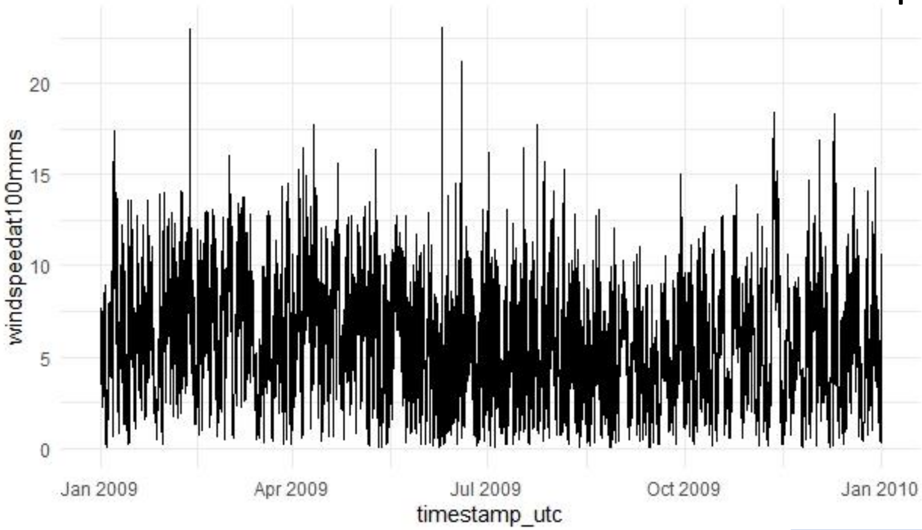
Charlotte NC, Boston MA, Boulder CO, Tucson AZ.

Data are retrieved from NREL's Developer Network: https://developer.nrel.gov/

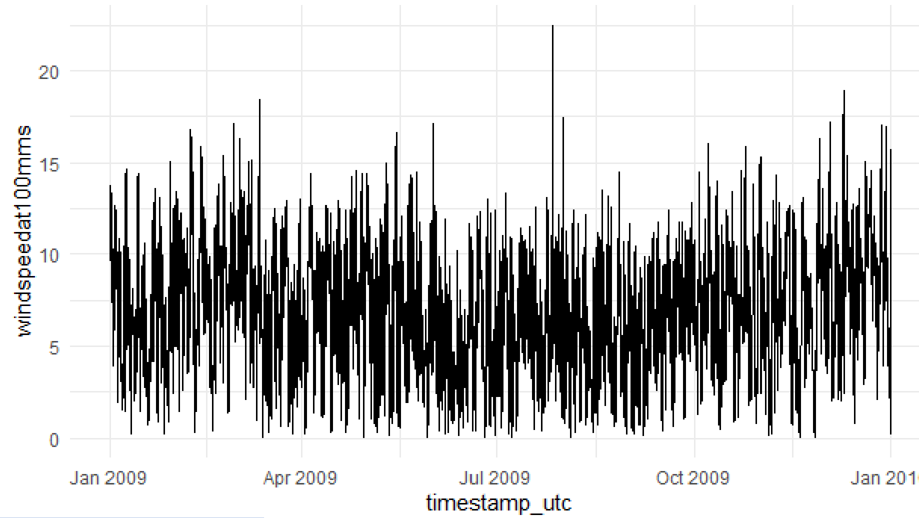
Wind Energy Resources Modeling

Time series of wind speed at height 100m (m/s)

Charlotte, NC

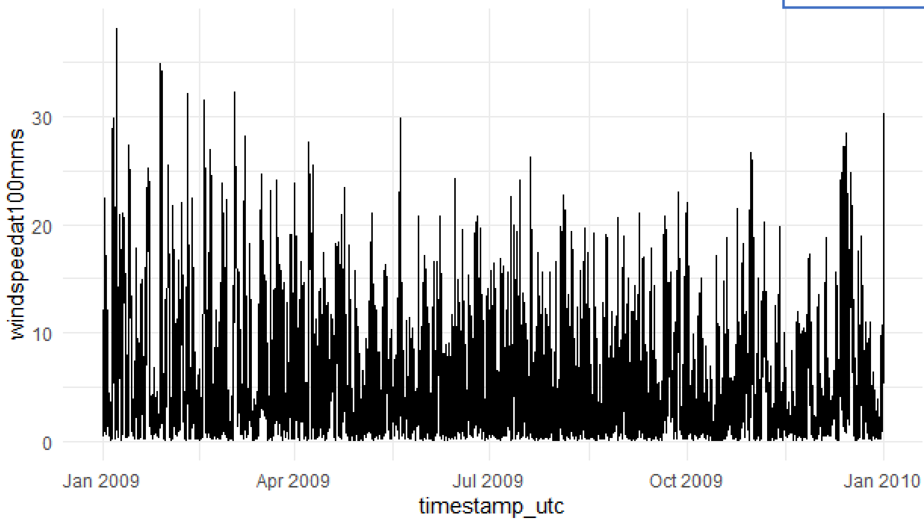


Boston, MA

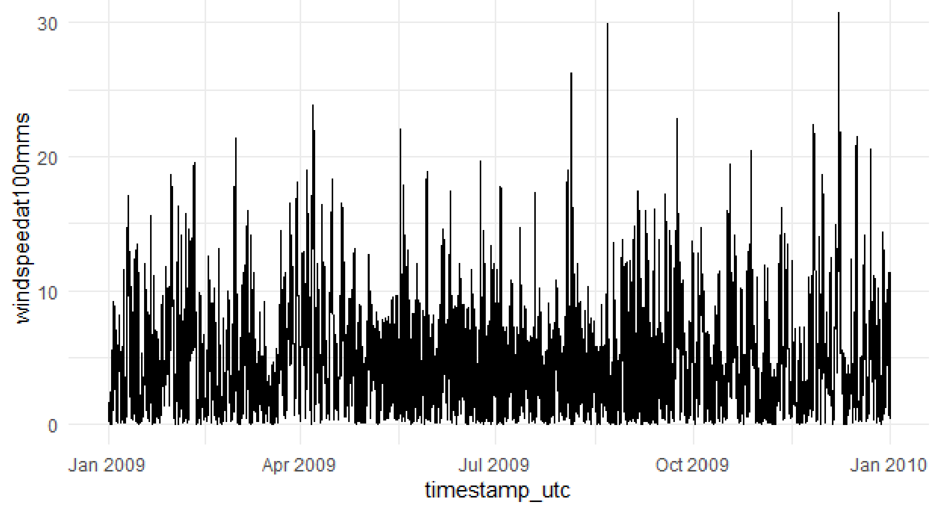


$$Pw = \frac{1}{2}\rho A \boldsymbol{v}^{3}$$

Boulder, CO



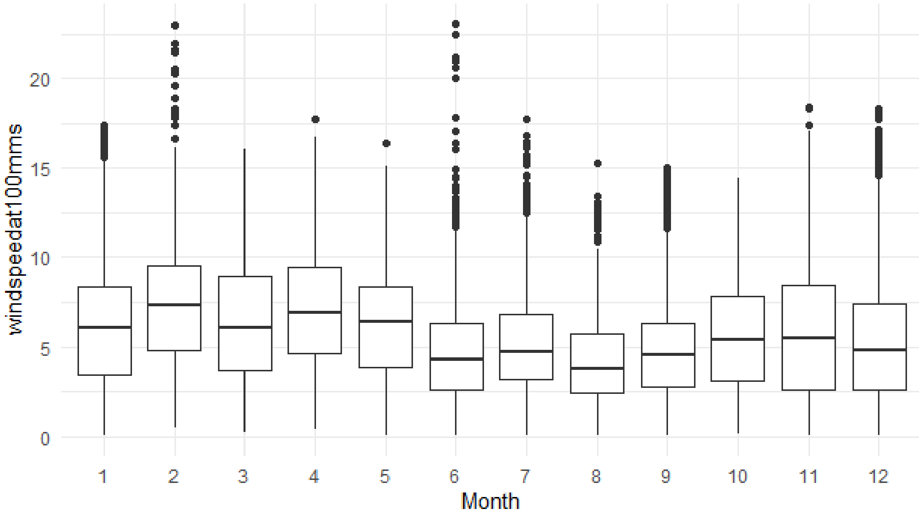
Tucson, AZ



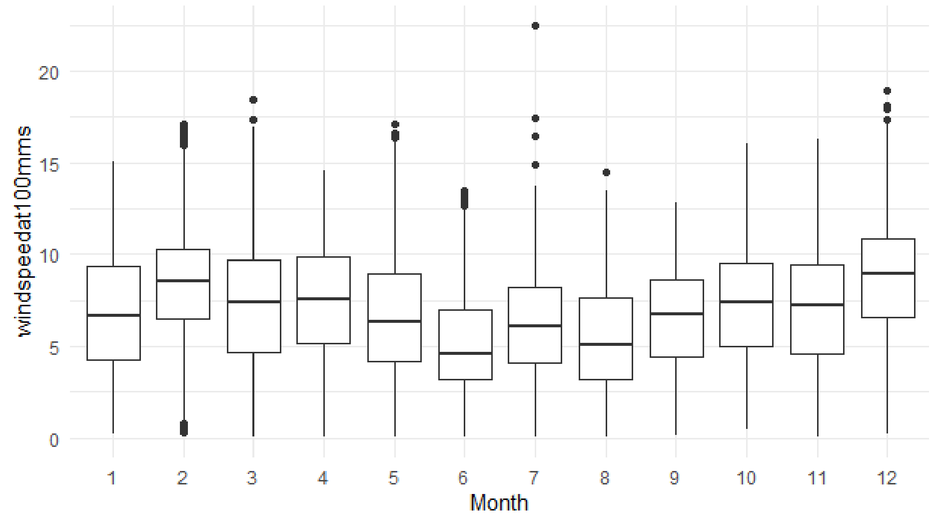
Wind Energy Resources Modeling

Boxplots of monthly distribution of wind speed

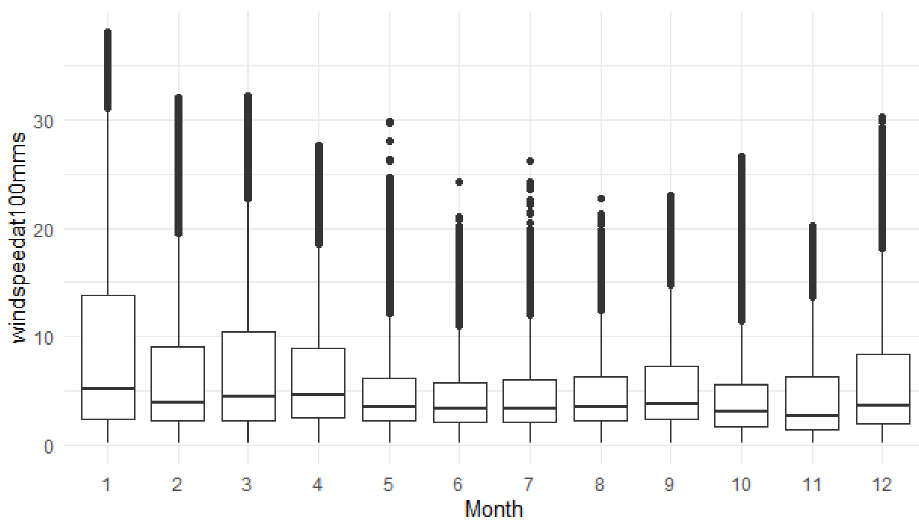
Charlotte, NC



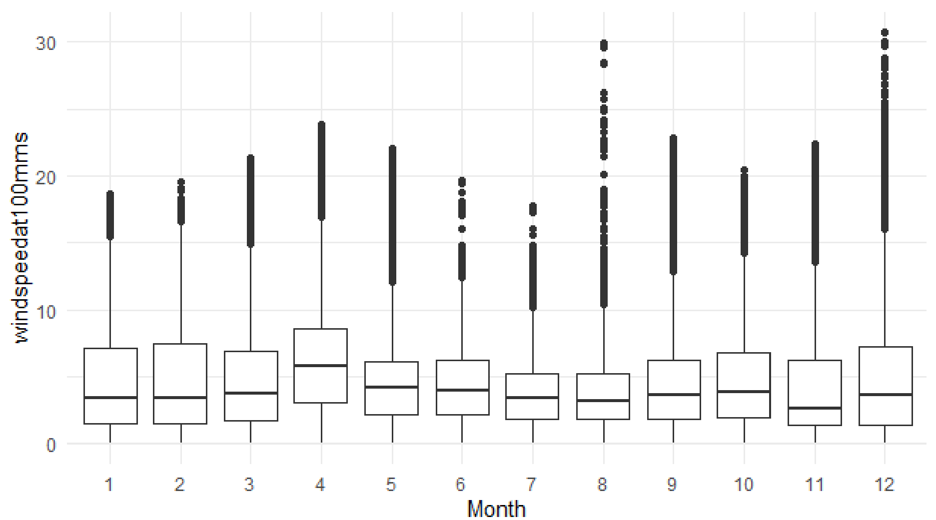
Boston, MA



Boulder, CO



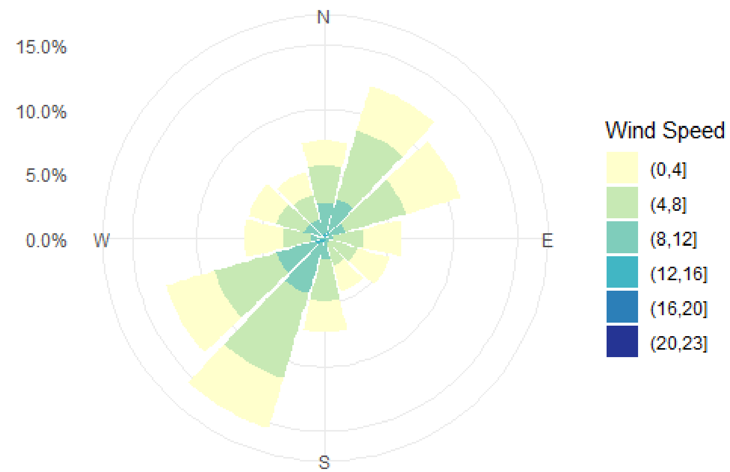
Tucson, AZ



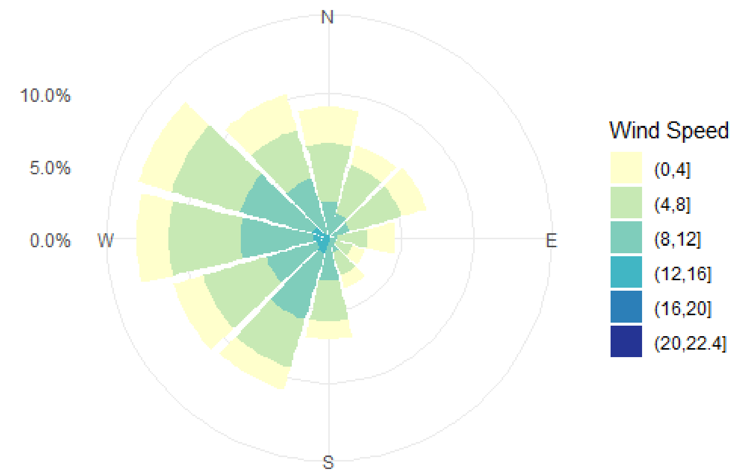
Wind Energy Resources Modeling

Wind Roses of Wind Speed

Charlotte, NC

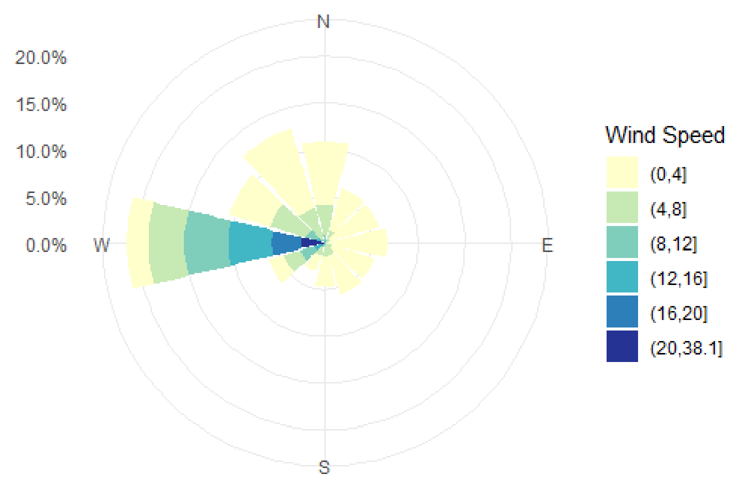


Boston, MA

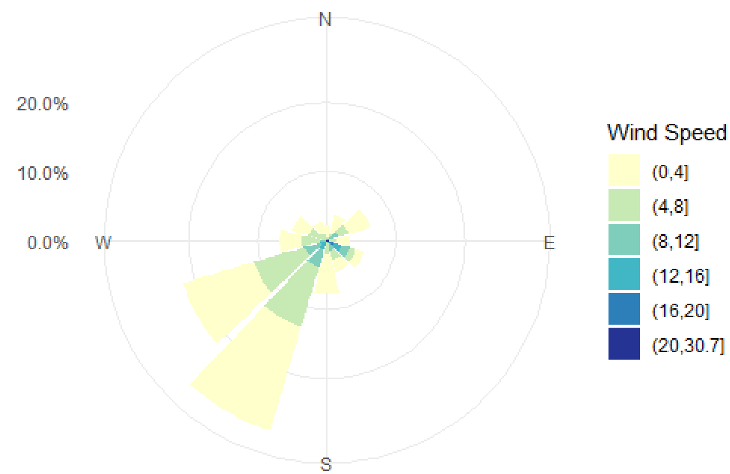


Distribution of wind direction and speed

Boulder, CO



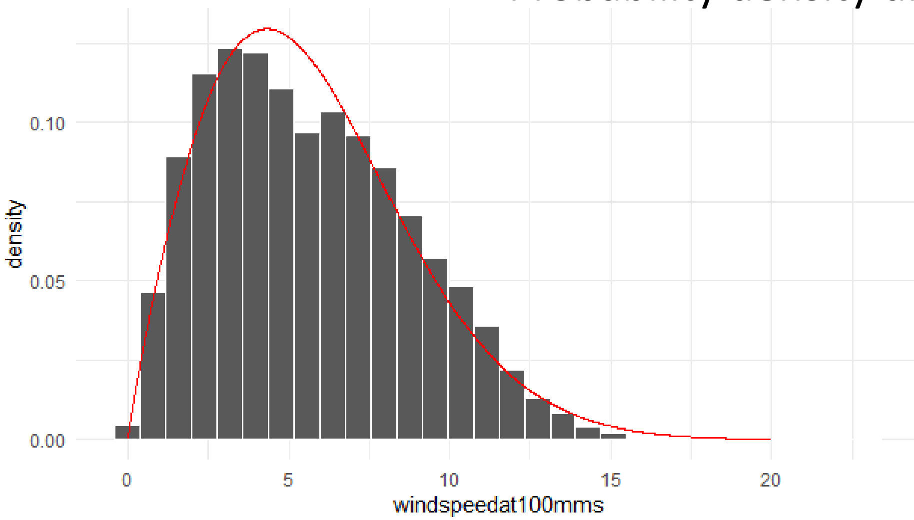
Tucson, AZ



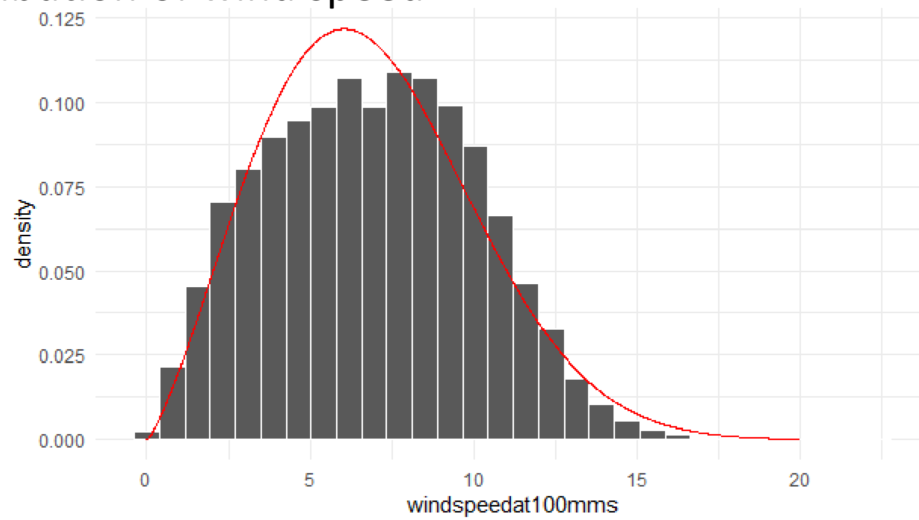
Wind Energy Resources Modeling

Probability density distribution of wind speed

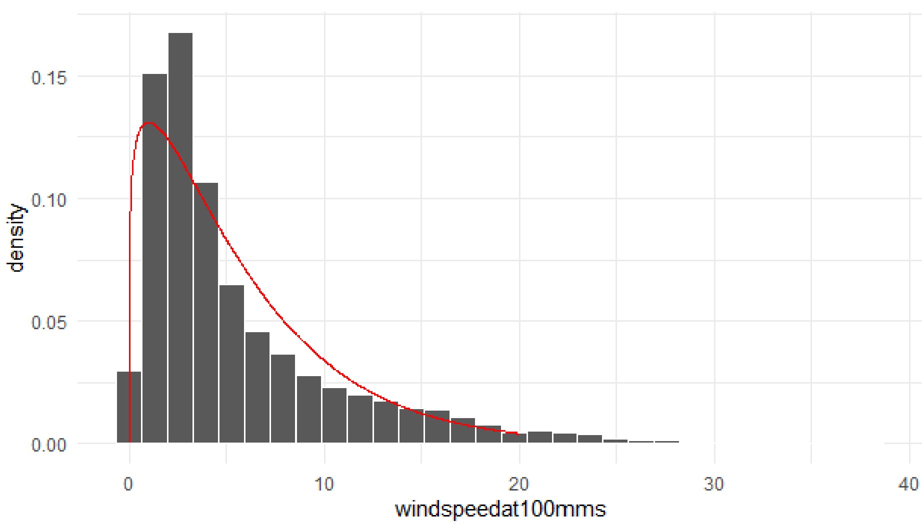
Charlotte, NC



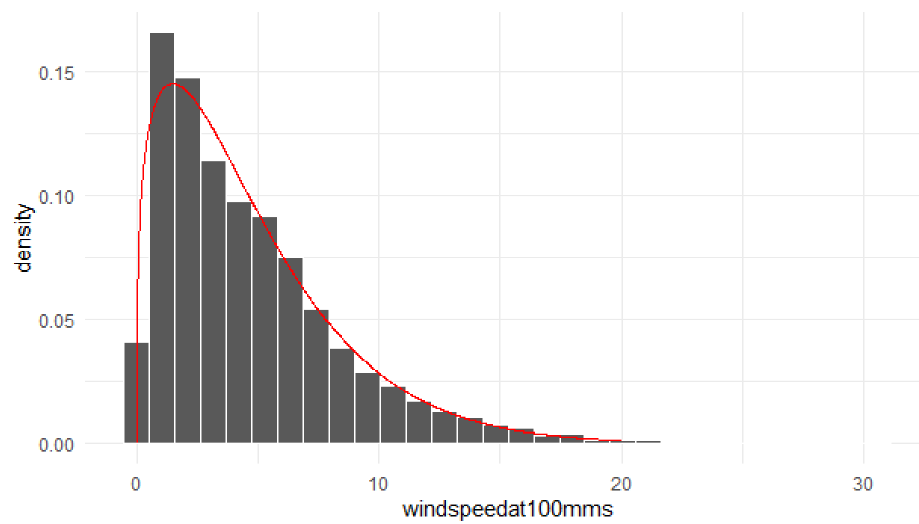
Boston, MA



Boulder, CO



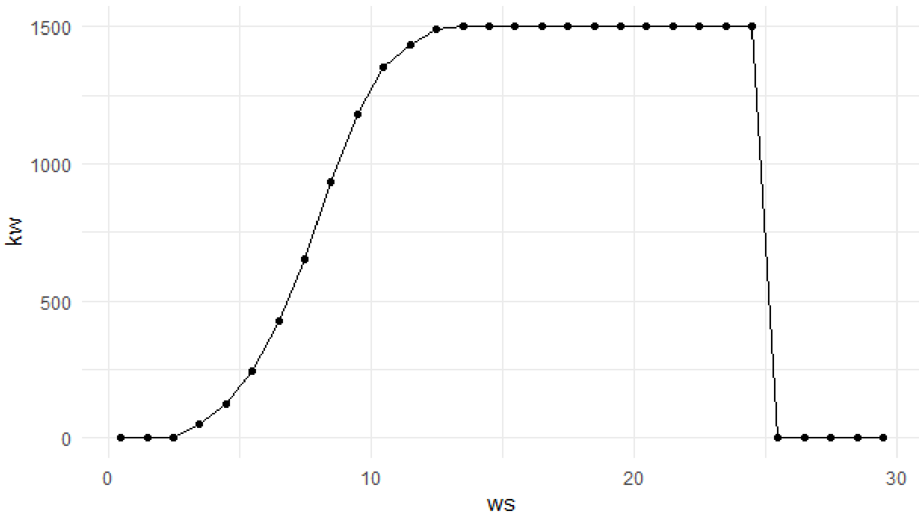
Tucson, AZ



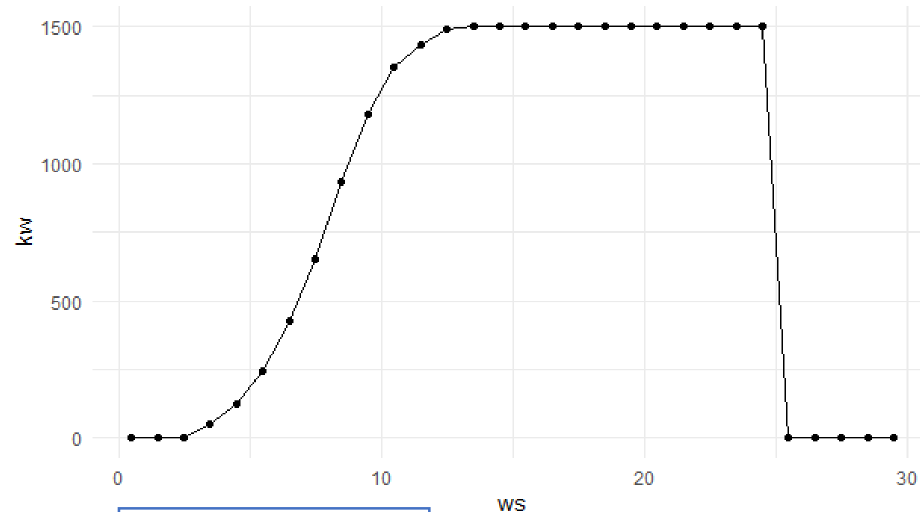
Wind Energy Resources Modeling

Wind turbine GE 1.5SLE 77m is utilized for modeling

Charlotte, NC



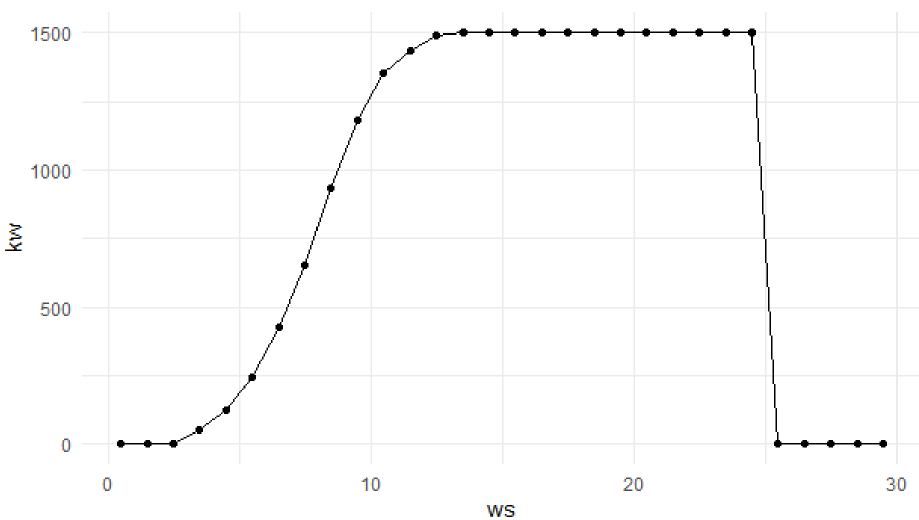
Boston, MA



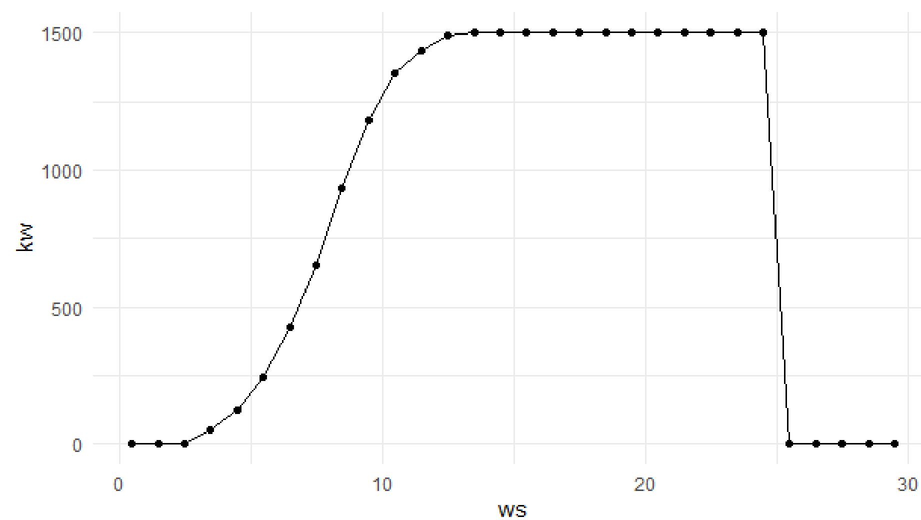
The wind power curve for GE 1.5SLE 77m to covert the wind speed to wind power

$$\boxed{Pw = \frac{1}{2}\rho A v^3}$$

Boulder, CO



Tucson, AZ

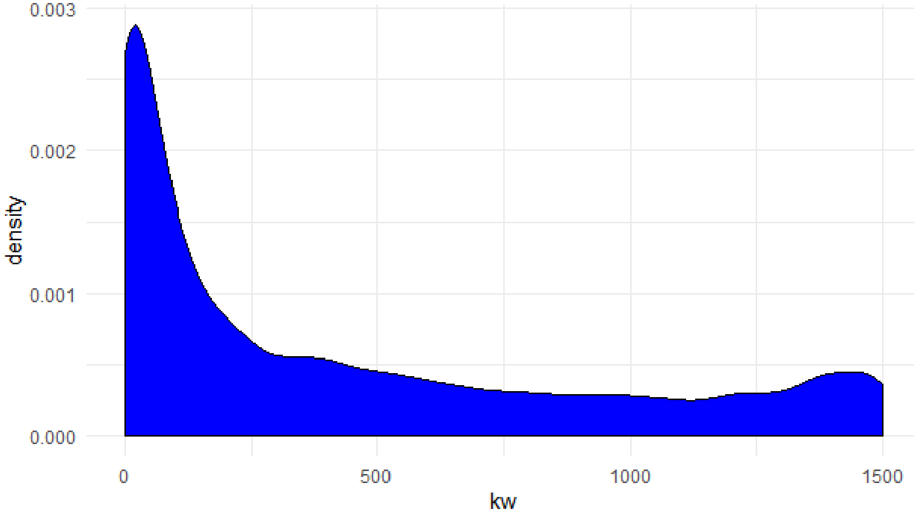


http://www.wind-power-program.com/Downloads/Databasepowercurves(May2017).zip

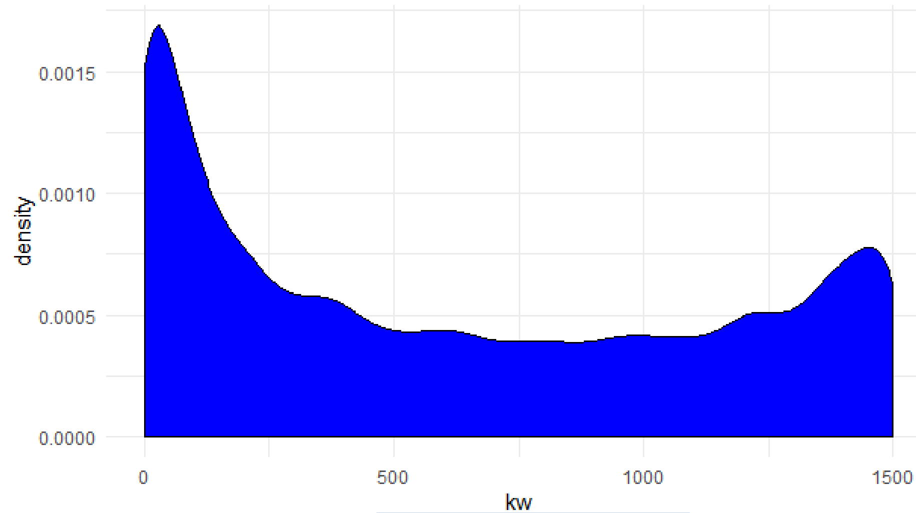
Wind Energy Resources Modeling

Probability density distribution of wind power

Charlotte, NC



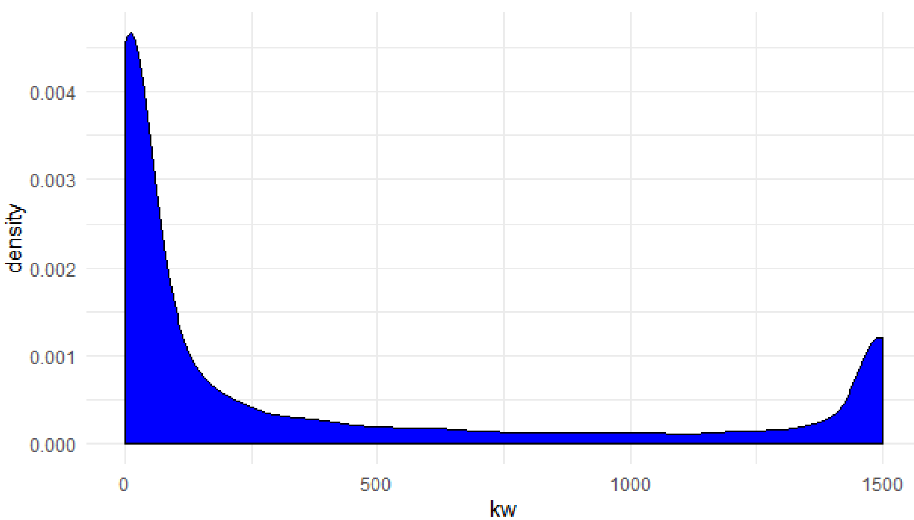
Boston, MA



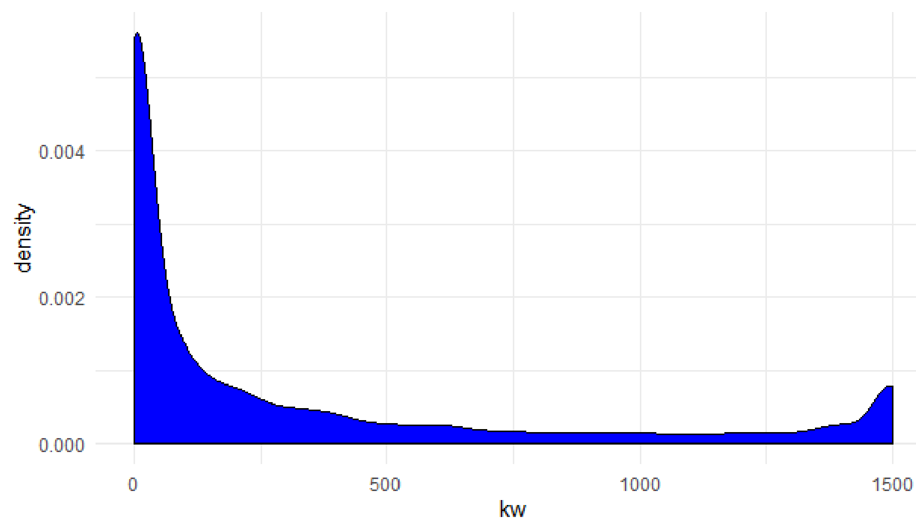
Considering other parameters such as air pressure, temperature and density at the given height=100m

$$\boxed{Pw = \frac{1}{2}\rho A v^3}$$

Boulder, CO



Tucson, AZ



Wind Energy Resources Modeling

Wind Energy Modeling
in 2009

Calculating the net capacity factor (NCF) for each month, then over the entire year

$$NCF=\frac{\text{The actual energy generated}}{\text{The possible maximum energy that could have been generated}}$$

$$NCF=\frac{\text{The actual energy }(MWh)}{\text{The capacity} * \text{time }(MWh)}$$

Charlotte, NC

Month	MWh	NCF
1	387.574	34.70%
2	455.725	45.20%
3	410.236	36.80%
4	456.256	42.20%
5	381.352	34.20%
6	193.475	17.90%
7	230.690	20.70%
8	141.379	12.70%
9	197.738	18.30%
10	310.630	27.80%
11	355.663	32.90%
12	298.279	26.70%

Boston, MA

Month0	MWh	NCF
1	467.945	41.90%
2	584.361	58.00%
3	510.499	45.70%
4	512.191	47.40%
5	420.662	37.70%
6	239.808	22.20%
7	354.663	31.80%
8	285.923	25.60%
9	396.328	36.70%
10	504.488	45.20%
11	471.683	43.70%
12	691.553	62.00%

Boulder, CO

Month	MWh	NCF
1	413.396	37.00%
2	288.217	28.60%
3	382.094	34.20%
4	339.568	31.40%
5	222.077	19.90%
6	187.928	17.40%
7	216.100	19.40%
8	215.737	19.30%
9	268.648	24.90%
10	206.966	18.50%
11	224.898	20.80%
12	312.770	28.00%

Tucson, AZ

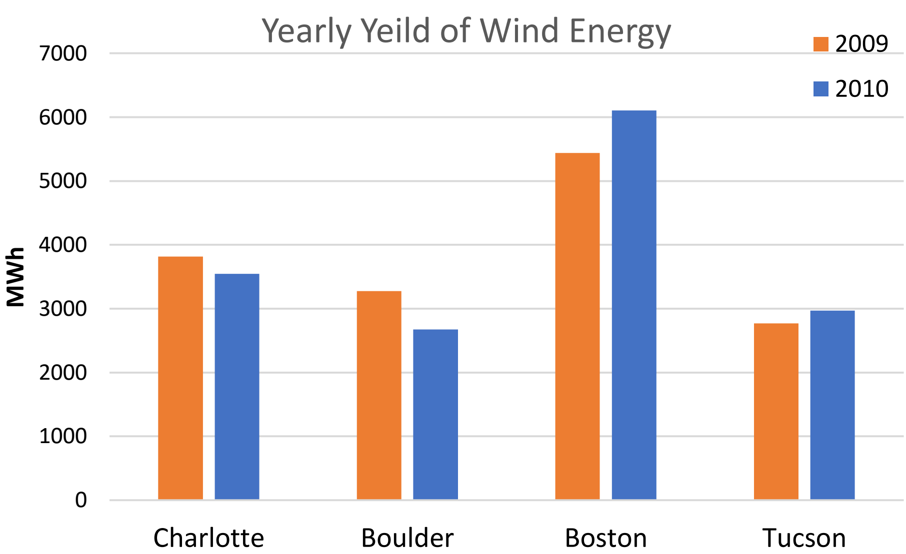
Month0	MWh	NCF
1	262.764	23.50%
2	247.664	24.60%
3	259.804	23.30%
4	378.228	35.00%
5	184.679	16.50%
6	188.630	17.50%
7	111.523	10.00%
8	143.448	12.90%
9	223.078	20.70%
10	258.261	23.10%
11	236.885	21.90%
12	274.958	24.60%

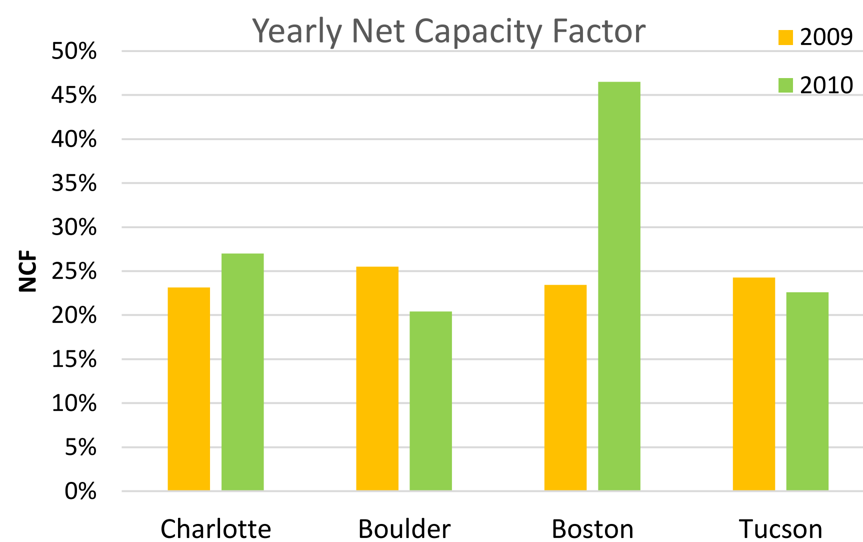
Wind Energy Resources Modeling

Wind Energy Modeling
in 2009 and 2010

2009	MWh	NCF
Charlotte	3818.9	29.1%
Boulder	3278.4	24.9%
Boston	5440.1	41.4%
Tucson	2769.9	21.1%

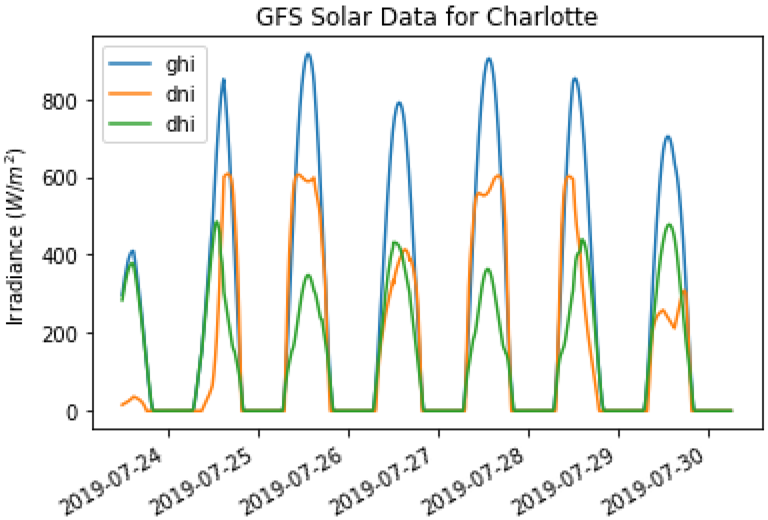
2010	MWh	NCF
Charlotte	3544.6	27.0%
Boulder	2676.9	20.4%
Boston	6107.7	46.5%
Tucson	2969.9	22.6%

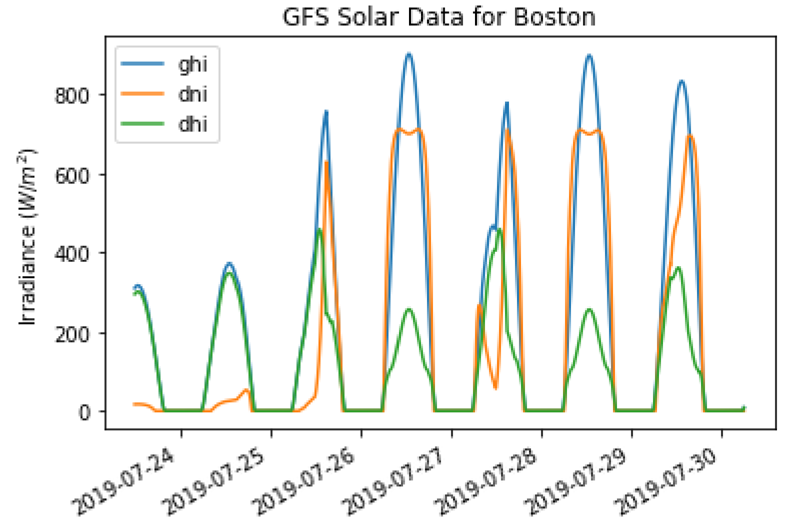


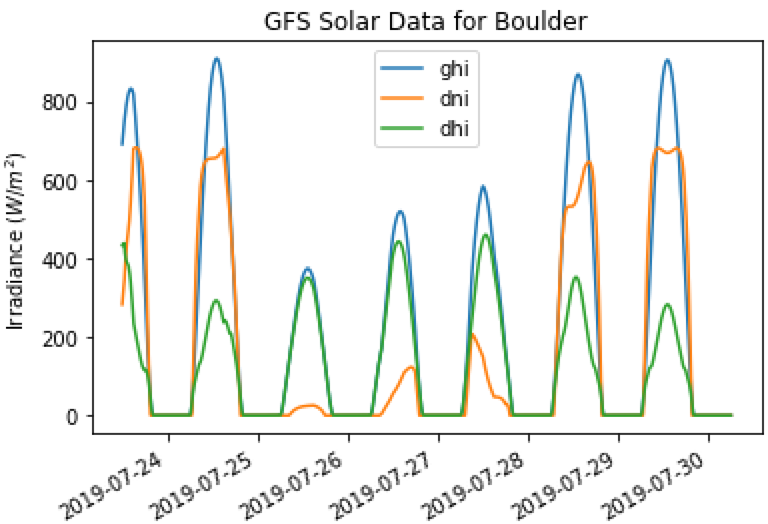


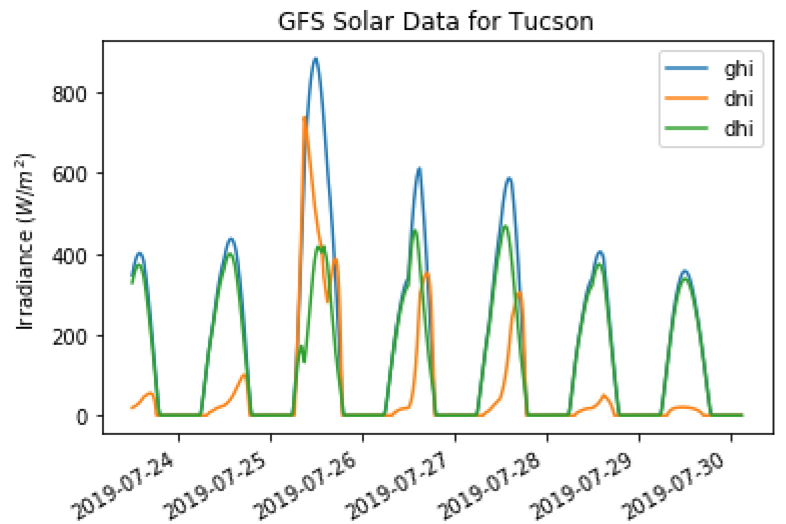
Solar Energy Resources Modeling

Time series of components of solar irradiance, GHI, DNI, DHI (W/m^2)



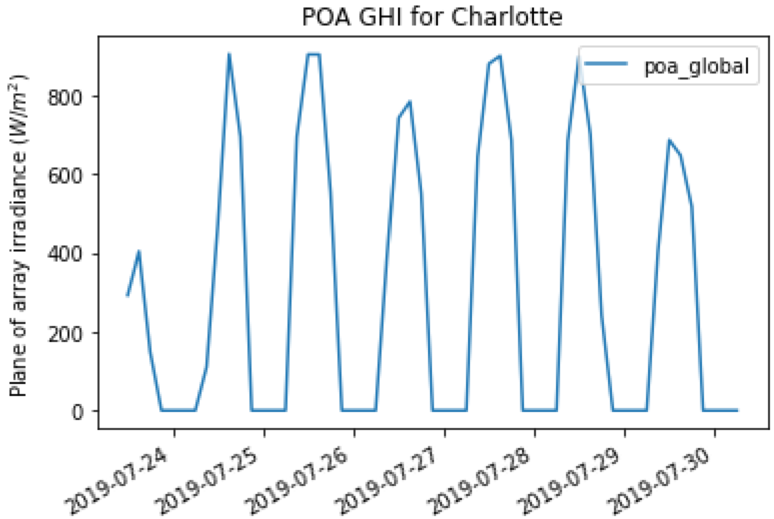


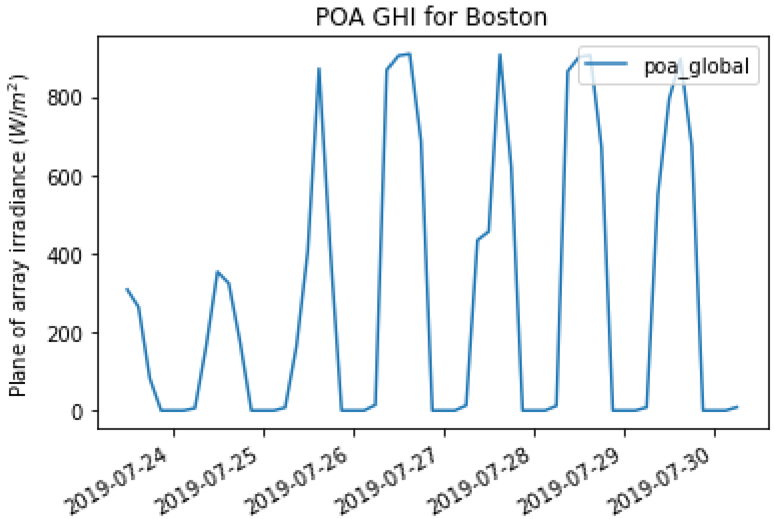


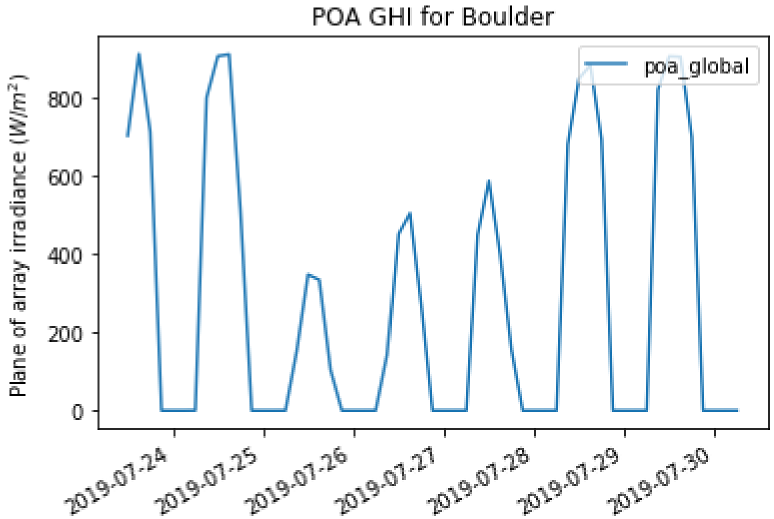


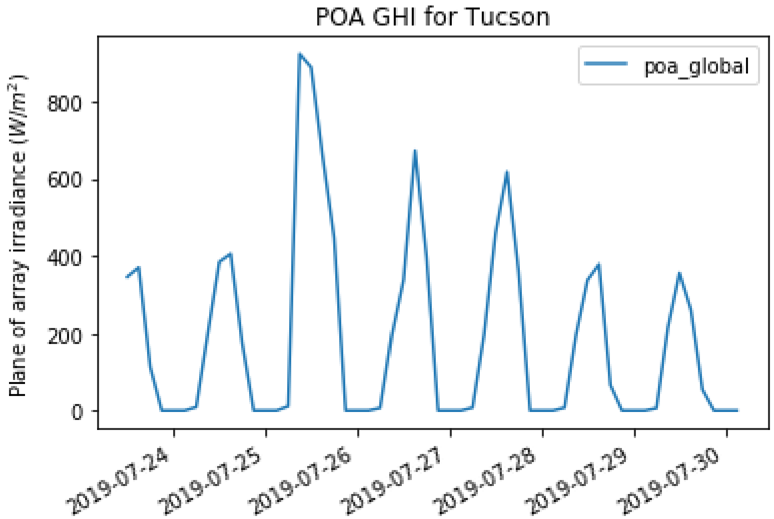
Solar Energy Resources Modeling

Global Horizontal Irradiance (GHI) at the plane of array (POA)



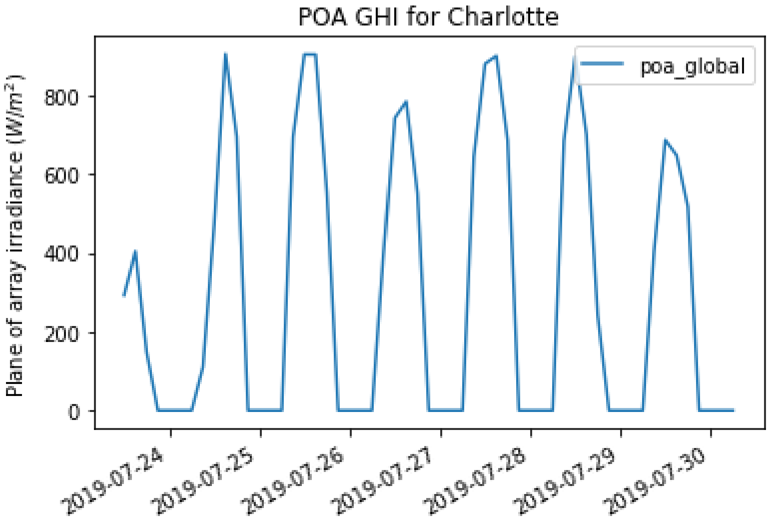


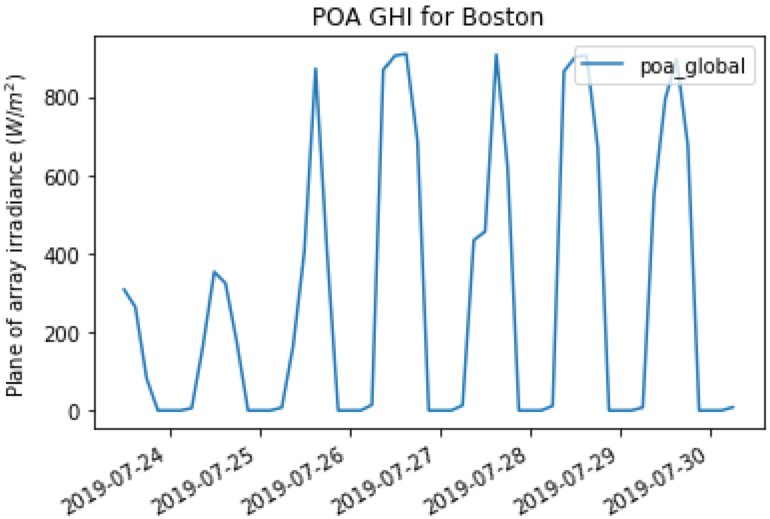


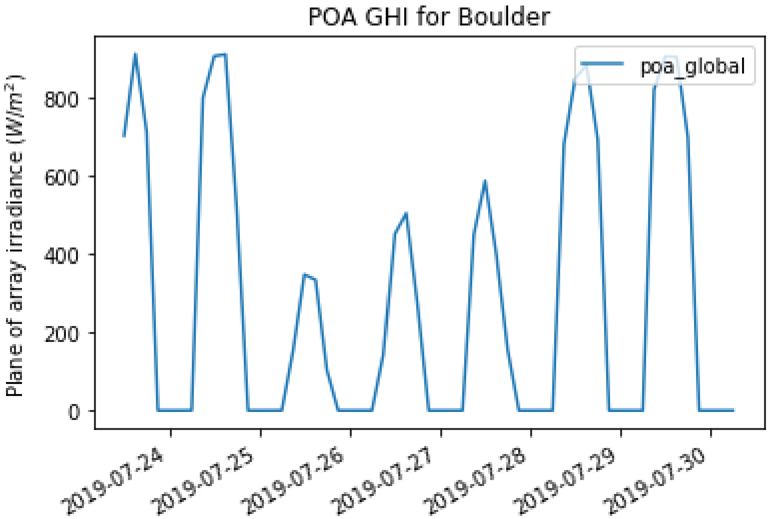


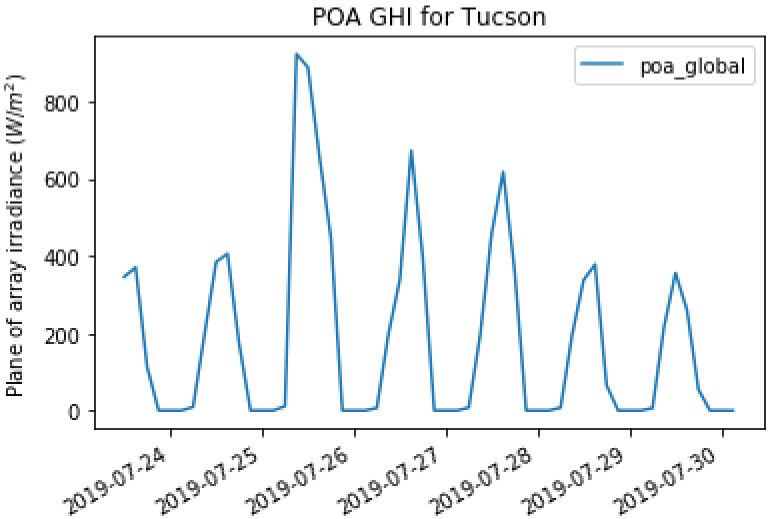
Solar Energy Resources Modeling

Global Horizontal Irradiance (GHI) at the plane of array (POA)









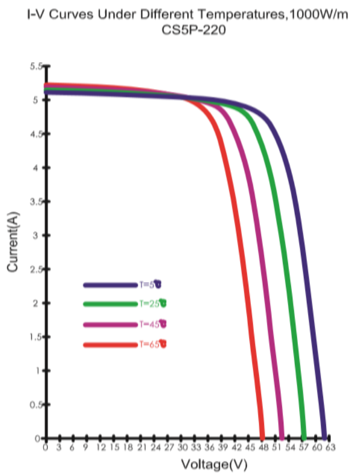
Solar Energy Resources Modeling

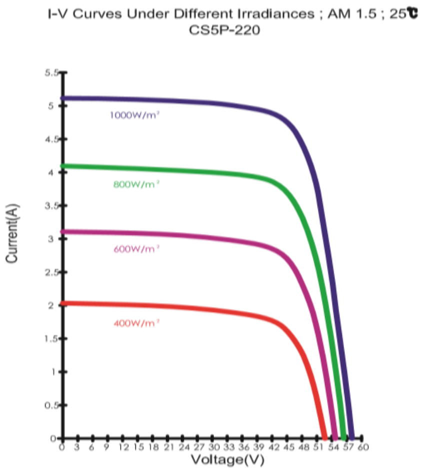
Convert GHI at the POA to Solar PV Power

To convert the solar irradiance to solar PV power, besides the cloud cover and radiative transfer model, other parameters are considered, such as air temperature at the plane of array, module orientation and efficiency η_{mpp}.

$$\boxed{P_{sol} \cong \eta_{mpp}(GHI_{POA}, Tm)GHI_{POA} * A}$$

PV Module CS5P-220M
Manufacturer: Canadian Solar
Type: Polycrystalline Cells
Power: 220 W (Maximum)
Length: 63.1in (1,602mm)
Width: 41.8in (1,061mm)
Depth: 1.6in (40mm)
https://www.solarover.com/panels/cs5p.pdf



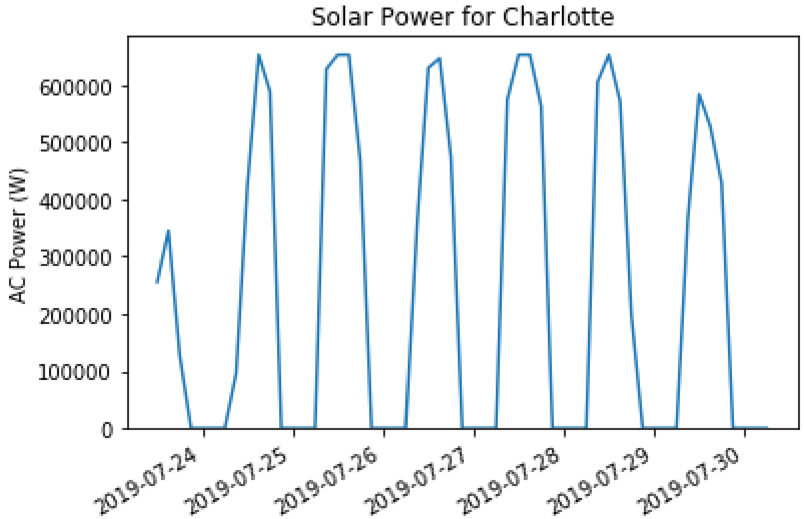


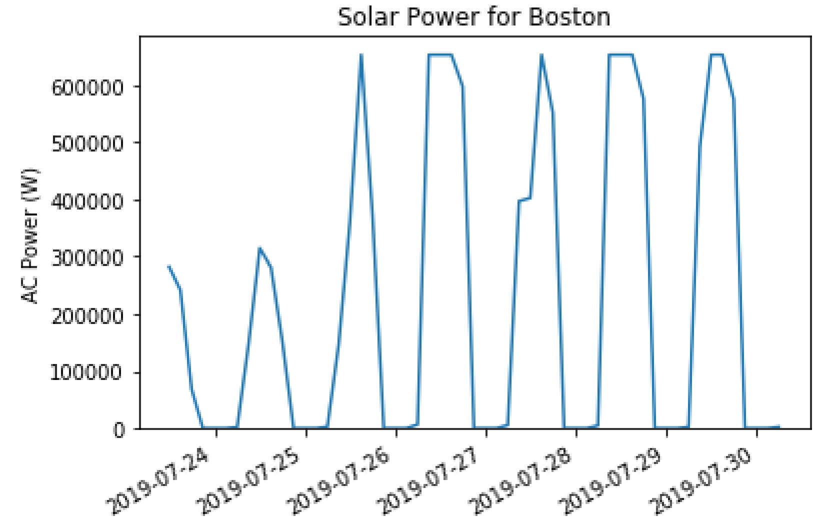
Pvlib Toolbox from Sandia and NREL's SAM package and Weather Data from GFS Global Model

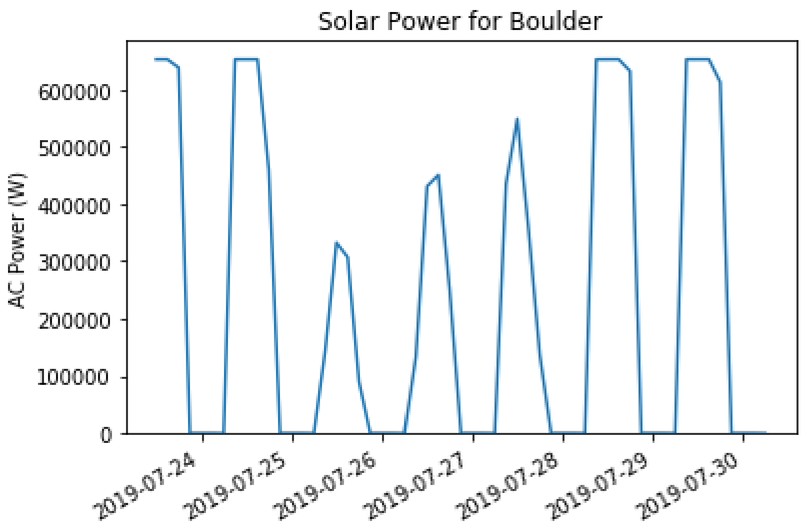
https://pvlib-python.readthedocs.io/en/latest/introexamples.html
https://pvlib-python.readthedocs.io/en/latest/forecasts.htm

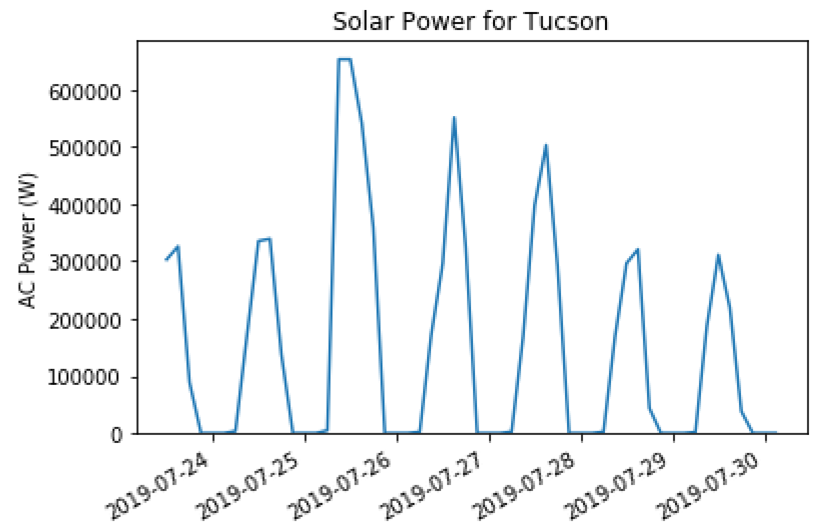
Solar Energy Resources Modeling

Time series of Solar Power (W), for a solar plant with 15*300 PV modules (220W for each)









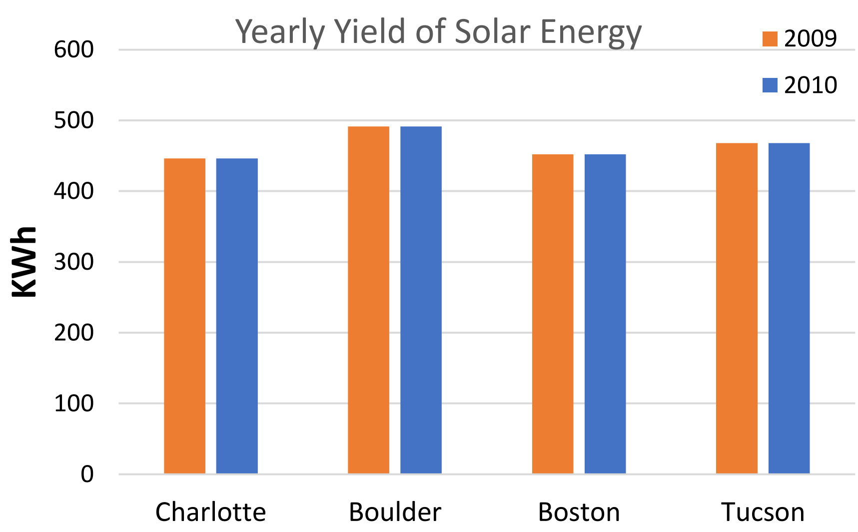
Solar Energy Resources Modeling

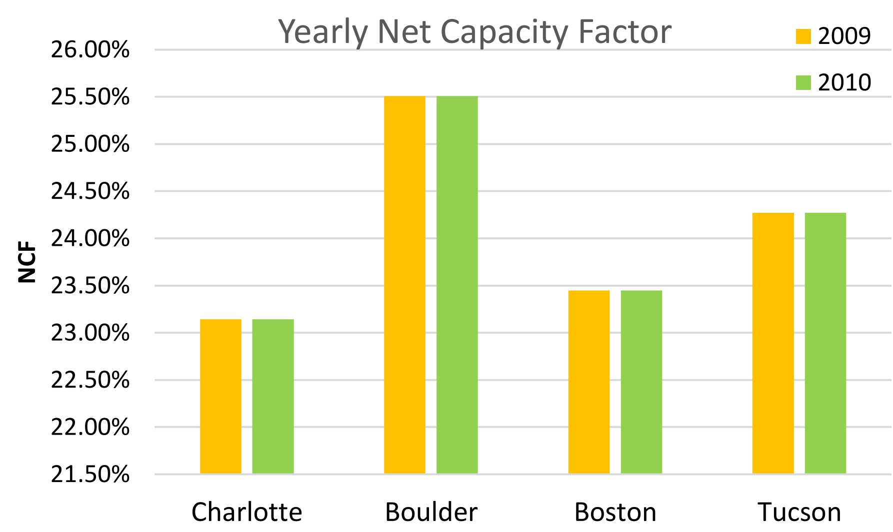
For 2009 and 2010, as in the wind energy modeling

For 1 PV module (220W, **PV Module CS5P-220M**)

2009	Wh	NCF
Charlotte	446028	23.14%
Boulder	491571	25.51%
Boston	451885	23.45%
Tucson	467719	24.27%

2010	Wh	NCF
Charlotte	446035	23.14%
Boulder	491582	25.51%
Boston	451899	23.45%
Tucson	467726	24.27%

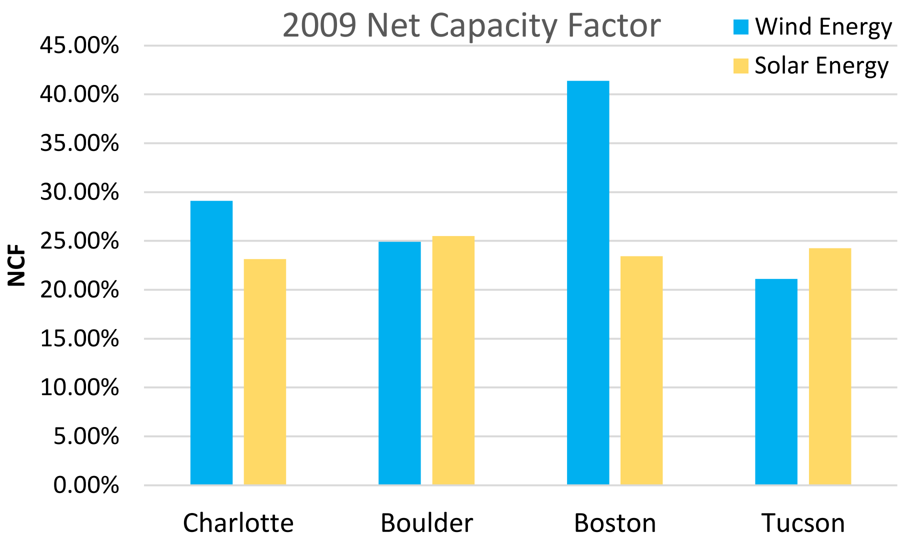




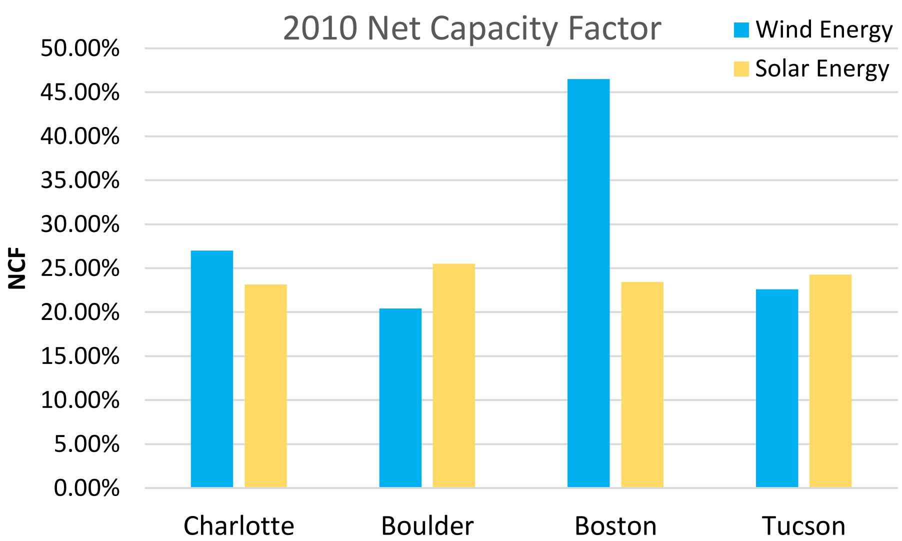
Wind and Solar Energy Resources Modeling

Comparison of NCF for Resources of Wind & Solar Energy

2009	NCF	
	Wind Energy	Solar Energy
Charlotte	29.10%	23.14%
Boulder	24.90%	25.51%
Boston	41.40%	23.45%
Tucson	21.10%	24.27%



2010	NCF	
	Wind Energy	Solar Energy
Charlotte	27.00%	23.14%
Boulder	20.40%	25.51%
Boston	46.50%	23.45%
Tucson	22.60%	24.27%



Conclusion

The performance of wind and solar energy resources depends significantly on their location and weather conditions.

Further Work

Modeling and evaluate the wind and solar resources backed up by energy storage systems.

References

1. https://www.r-bloggers.com/time-series-analysis-with-wind-resource- assessment-in-r/
2. https://github.com/mhdella/AWEA_WRA_Working_Group/blob/master/Example_Wind_Resource_Assessment_Using_R.md
3. https://pvlib-python.readthedocs.io/en/latest/introexamples.html
4. Stein, J. S., Holmgren, W. F., Forbess, J., & Hansen, C. W. (2016, June). PVLIB: Open source photovoltaic performance modeling functions for Matlab and Python. In *2016 ieee 43rd photovoltaic specialists conference (pvsc)* (pp. 3425-3430). IEEE.
5. Blair, N., Dobos, A. P., Freeman, J., Neises, T., Wagner, M., Ferguson, T., ... & Janzou, S. (2014). *System advisor model, sam 2014.1. 14: General description* (No. NREL/TP-6A20-61019). National Renewable Energy Lab.(NREL), Golden, CO (United States).

Thanks for Listening

Any Question?

Mohamed Abuella
https://mohamedabuella.github.io

http://epic.uncc.edu/
Energy Production and Infrastructure Center
University of North Carolina at Charlotte
UNC CHARLOTTE