

Wind and Solar Energy Resources Modeling and Analysis

Technical Presentation

By

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The University of North Carolina at Charlotte

August 9th, 2019

Presentation Outline

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graph TD; A[Presentation Outline] --> B[Wind Energy Resources Modeling]; A --> C[Solar Energy Resources Modeling];
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**Wind Energy Resources
Modeling**

**Solar Energy Resources
Modeling**

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.

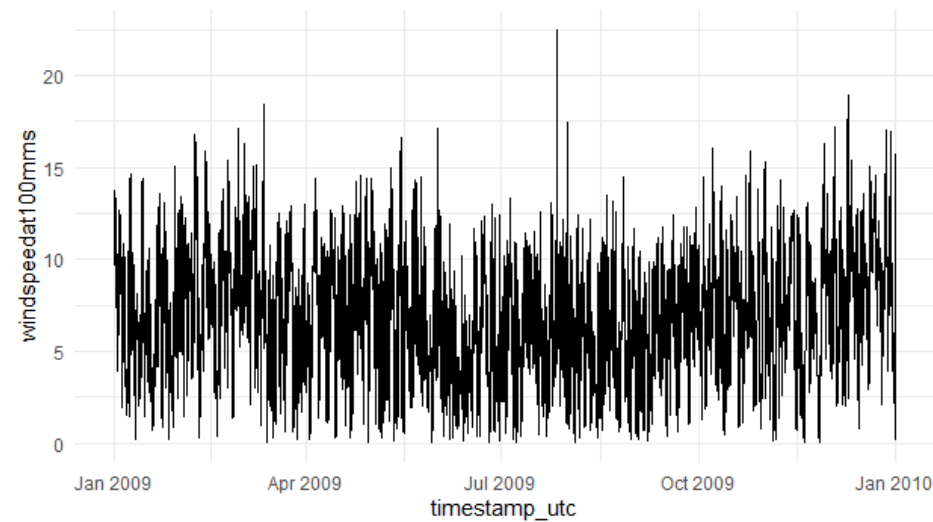
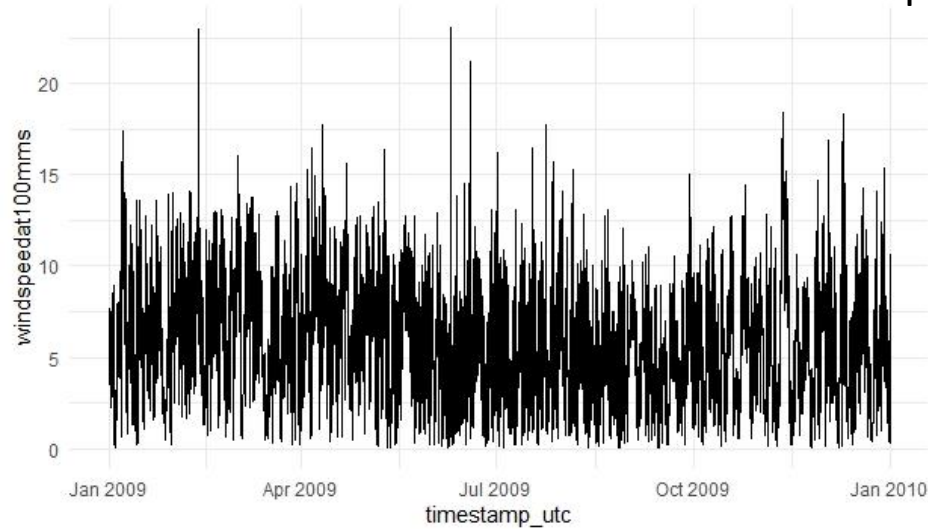
Data are retrieved from NREL's Developer Network: <https://developer.nrel.gov/>

Wind Energy Resources Modeling

Charlotte, NC

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

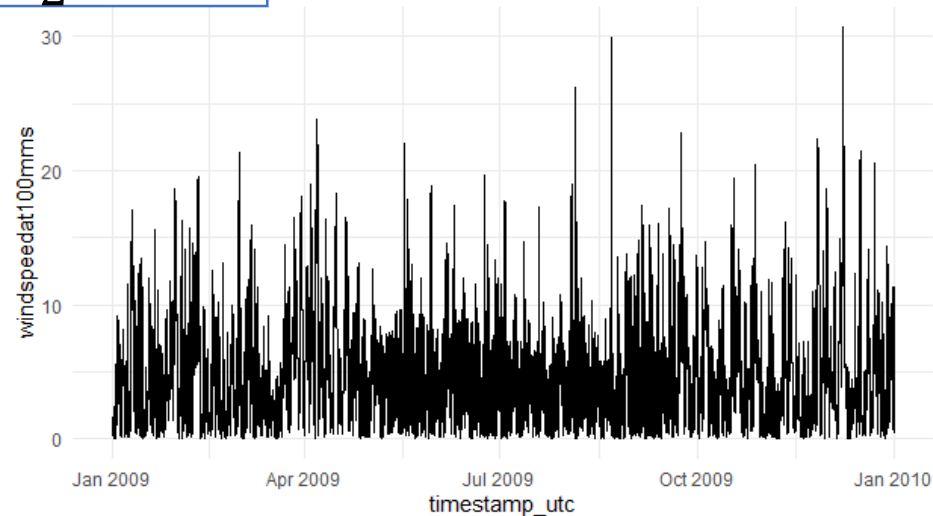
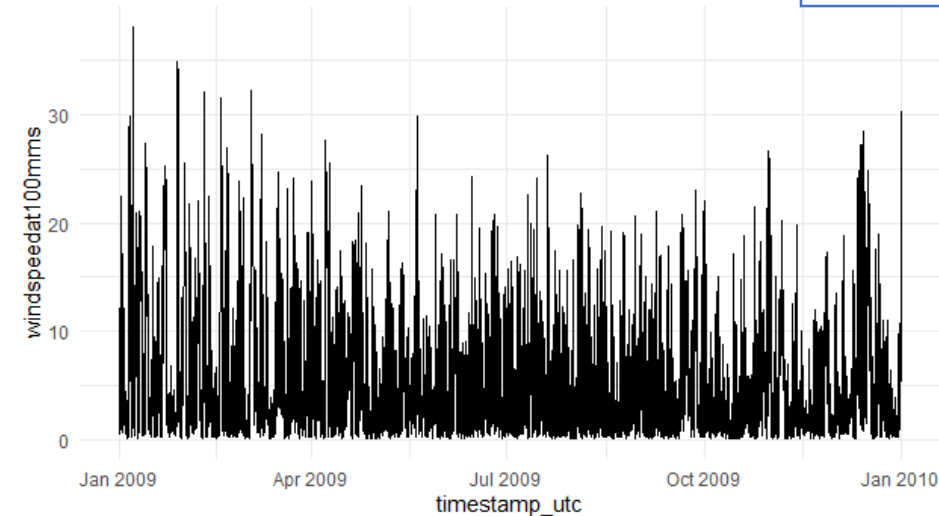
Boston, MA



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

Boulder, CO

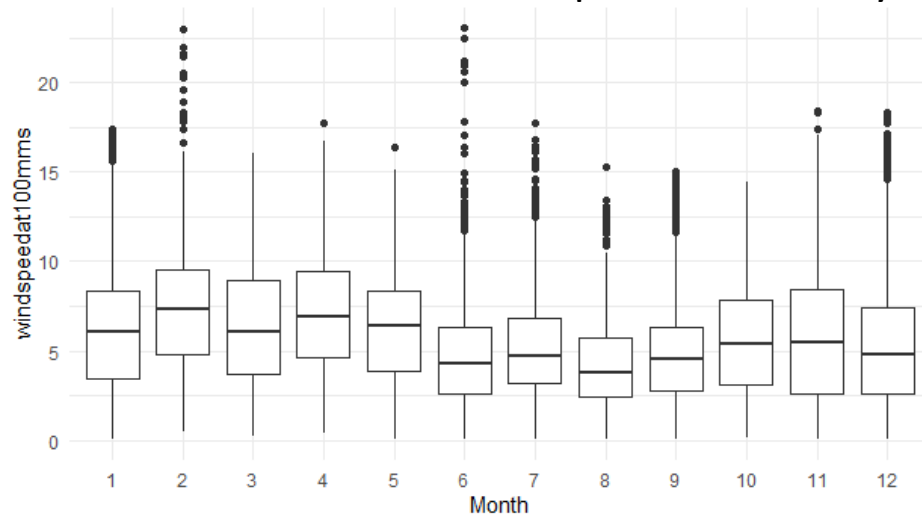
Tucson, AZ



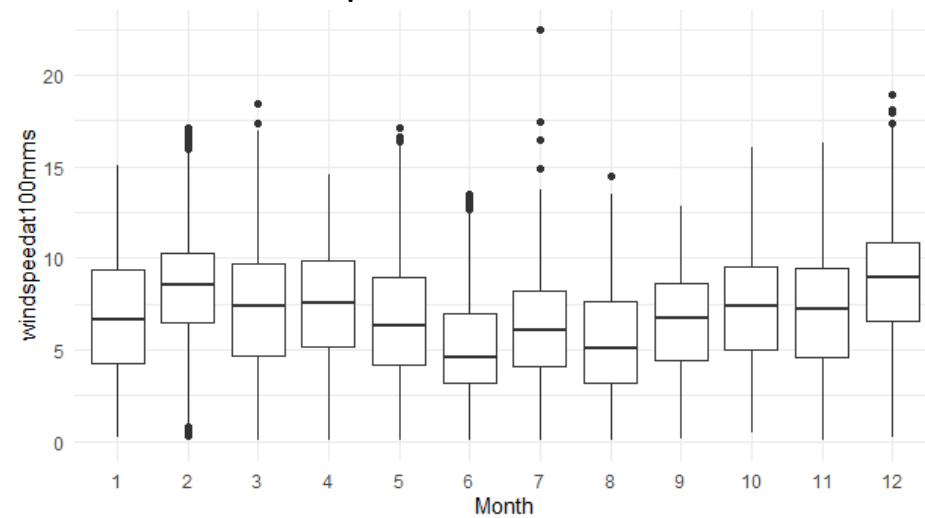
Wind Energy Resources Modeling

Boxplots of monthly distribution of wind speed

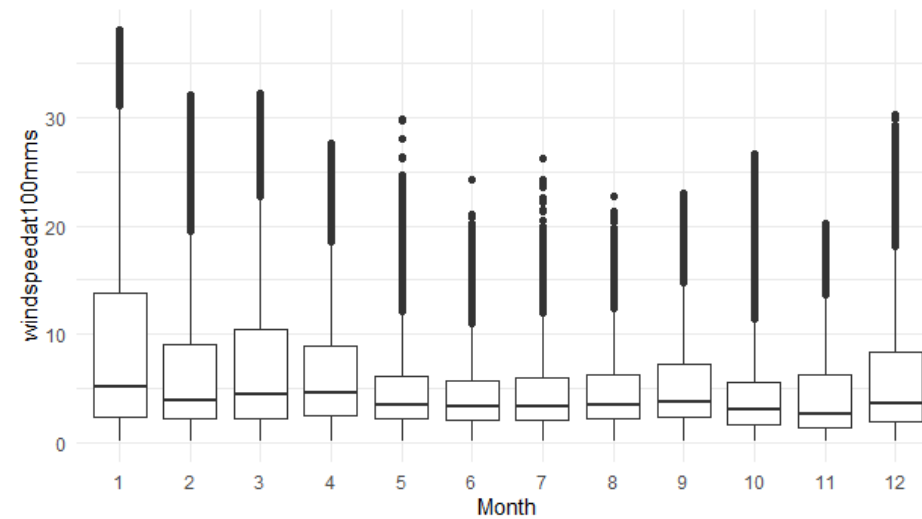
Charlotte, NC



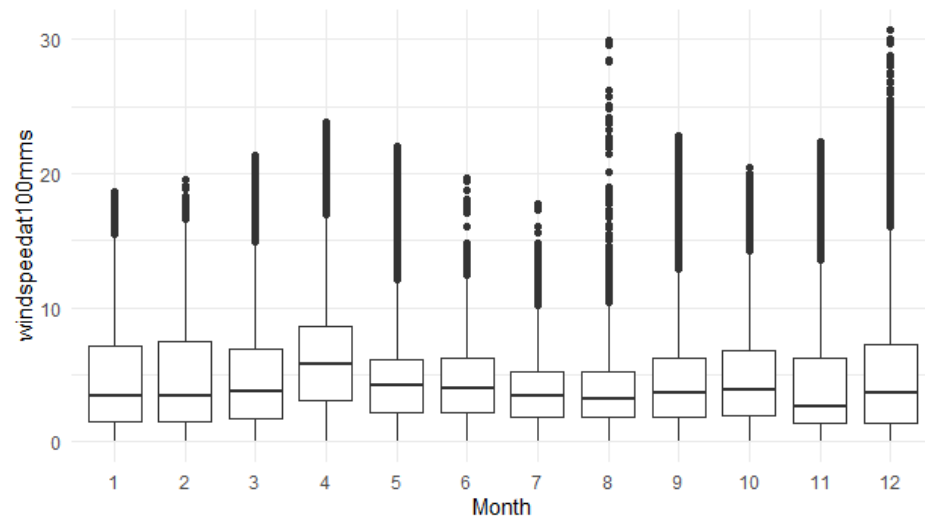
Boston, MA



Boulder, CO



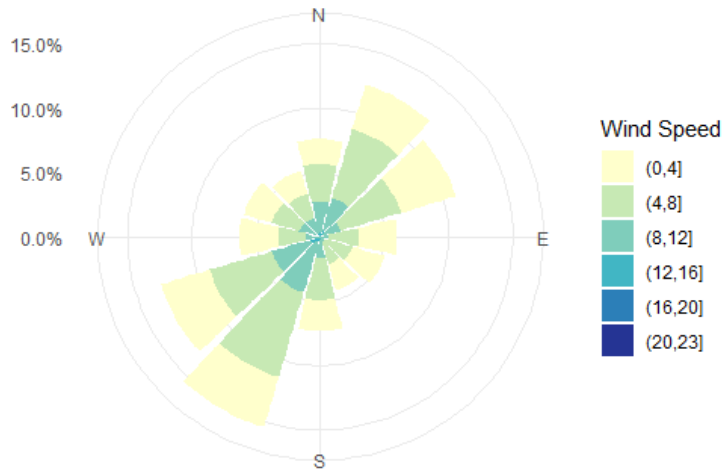
Tucson, AZ



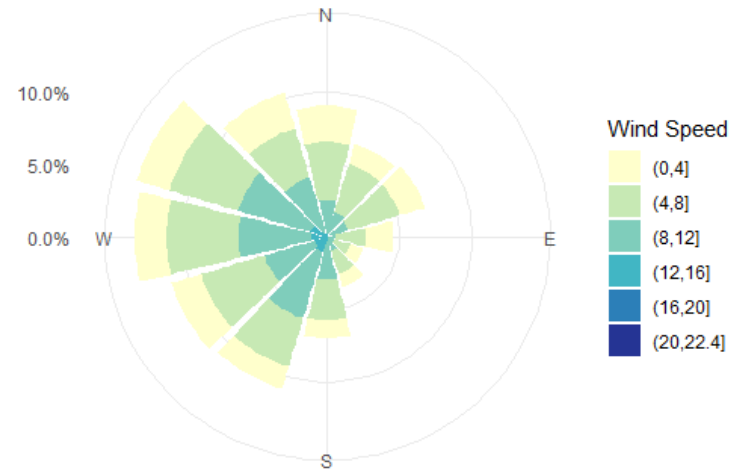
Wind Energy Resources Modeling

Wind Roses of Wind Speed

Charlotte, NC

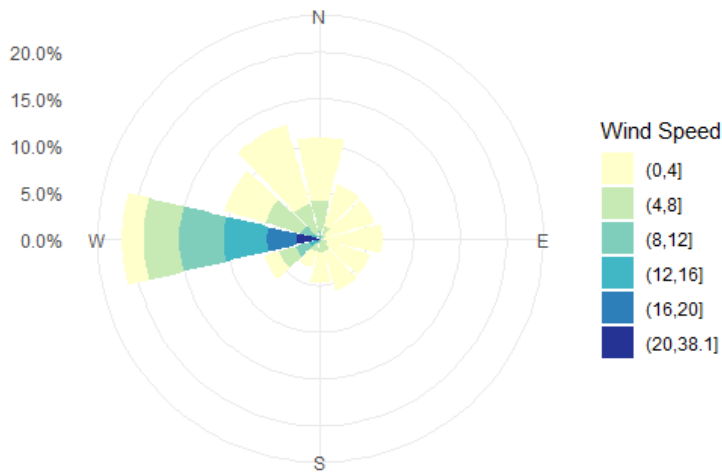


Boston, MA

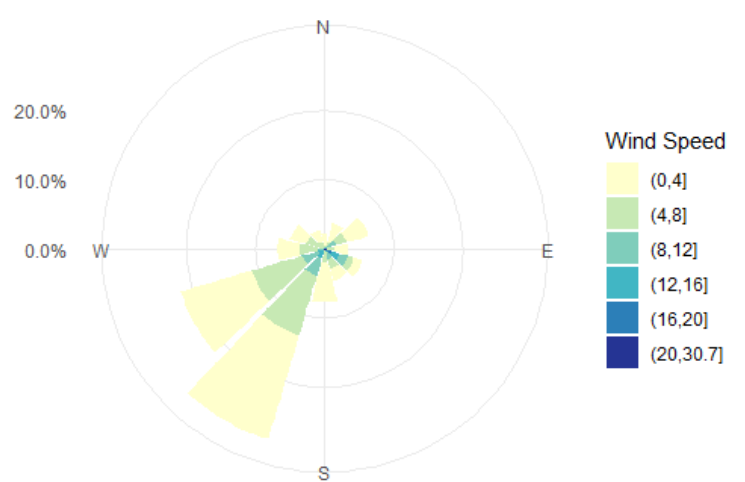


Distribution of wind direction and speed

Boulder, CO



Tucson, AZ

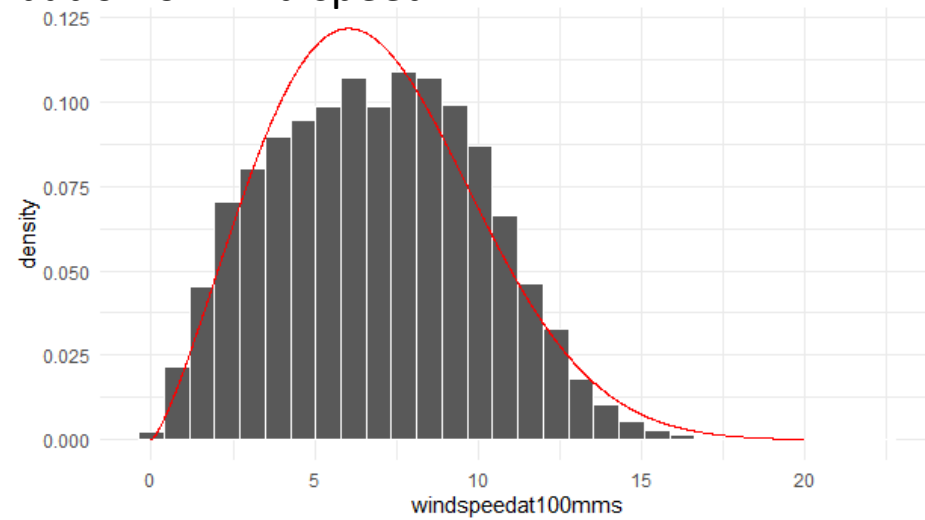
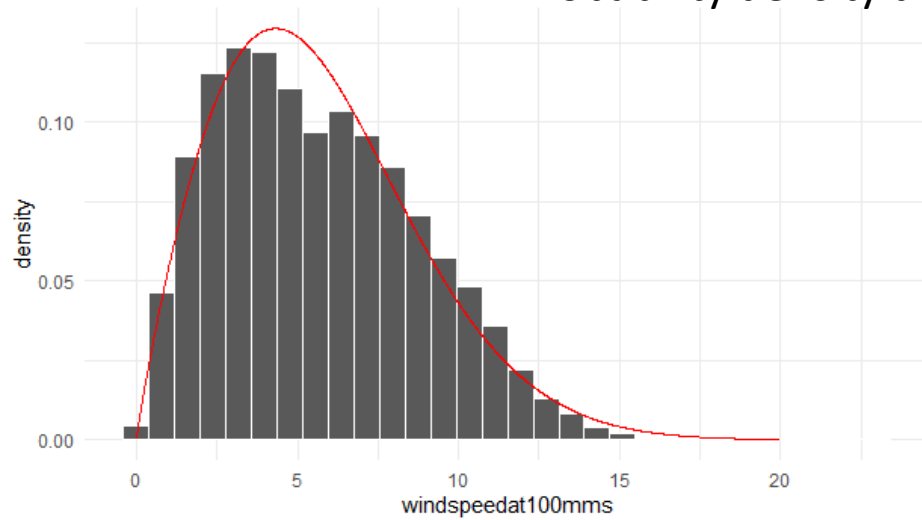


Wind Energy Resources Modeling

Charlotte, NC

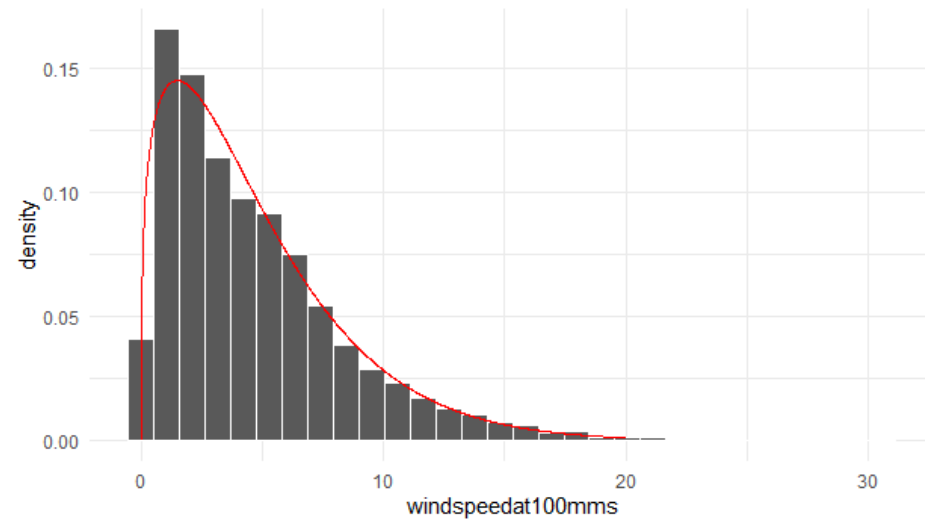
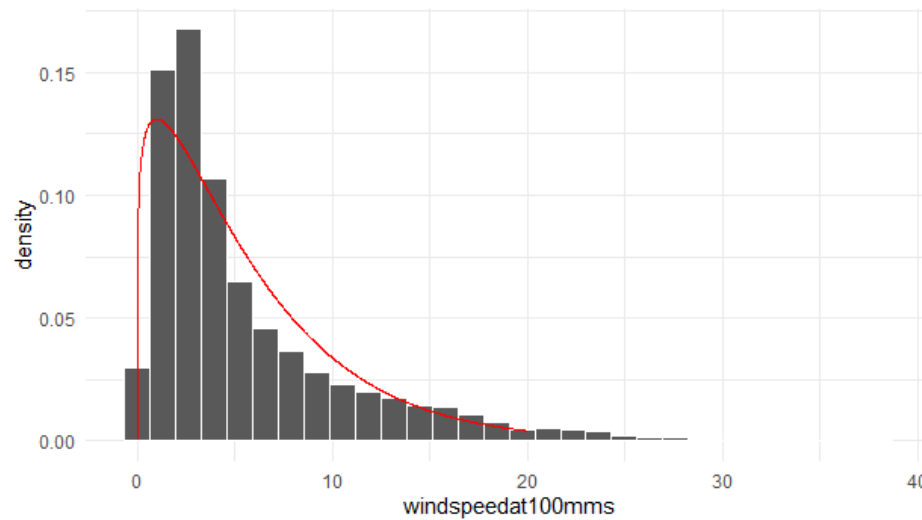
Probability density distribution of wind speed

Boston, MA



Boulder, CO

Tucson, AZ

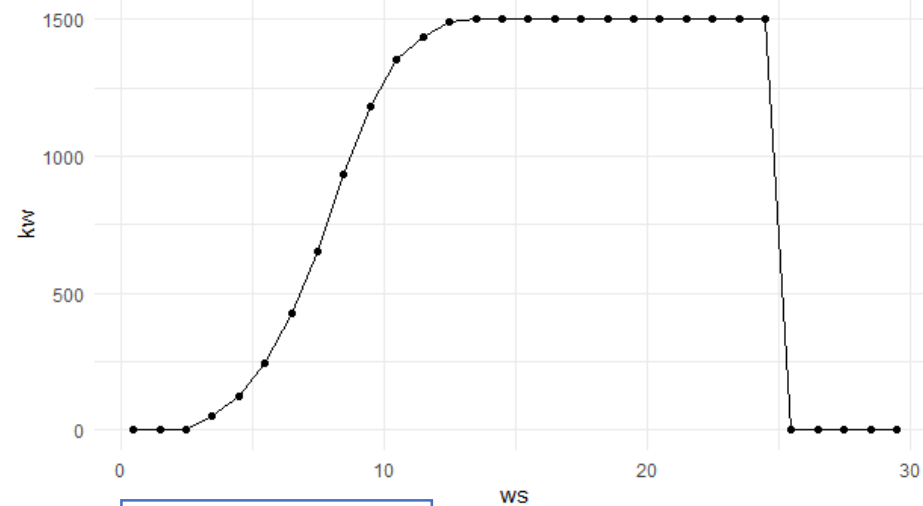
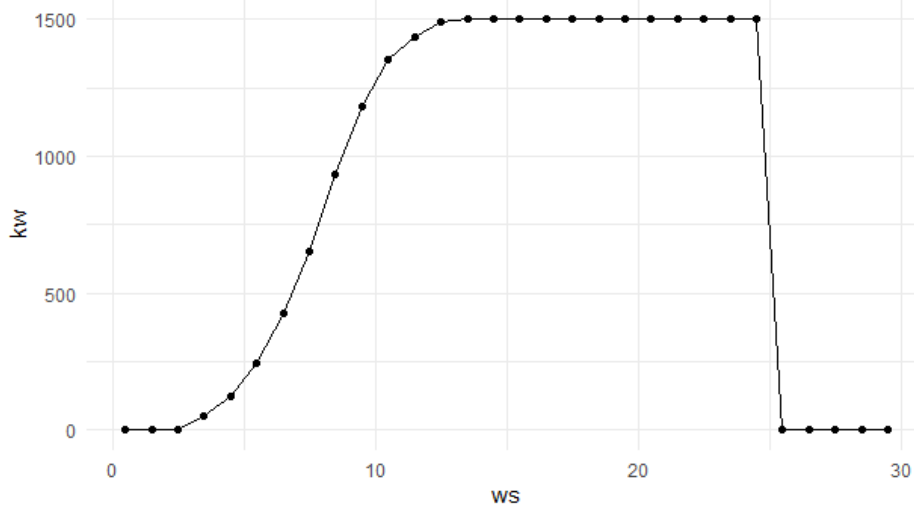


Wind Energy Resources Modeling

Wind turbine GE 1.5SLE 77m is utilized for modeling

Charlotte, NC

Boston, MA

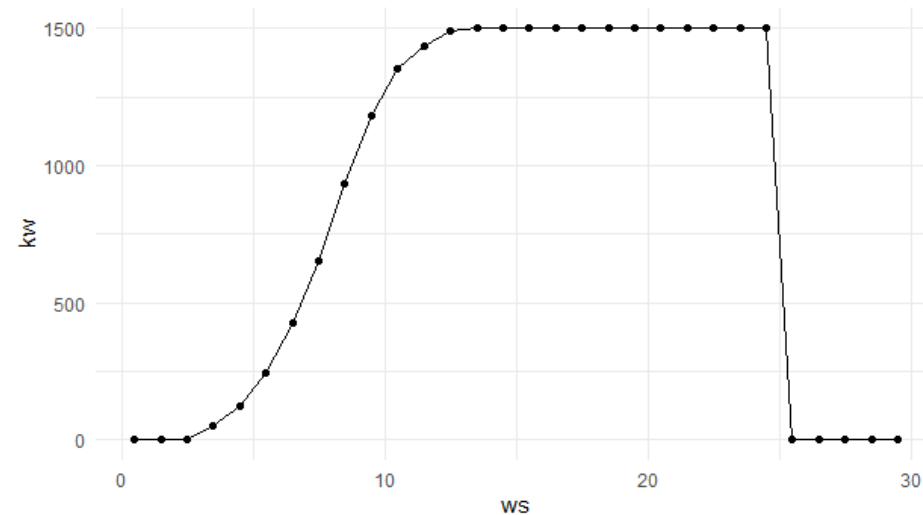
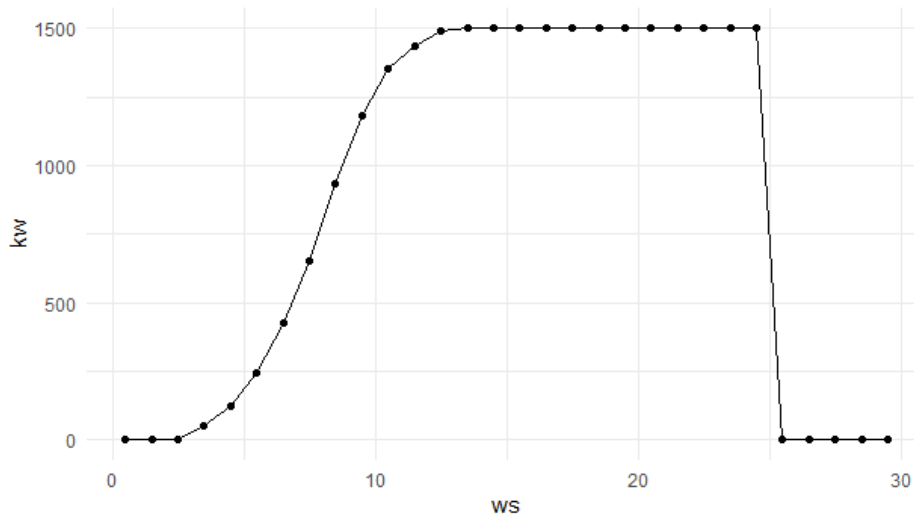


The wind power curve for GE 1.5SLE 77m to covert the wind speed to wind power

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

Boulder, CO

Tucson, AZ

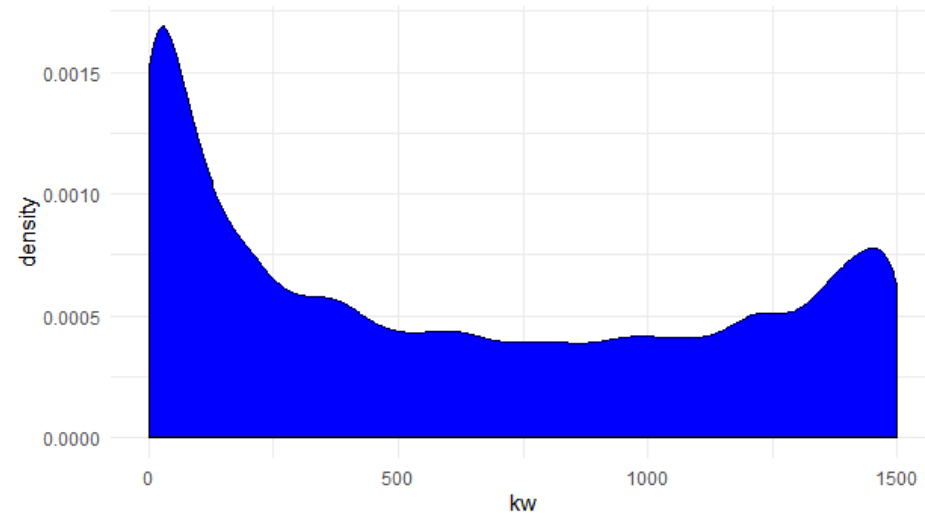
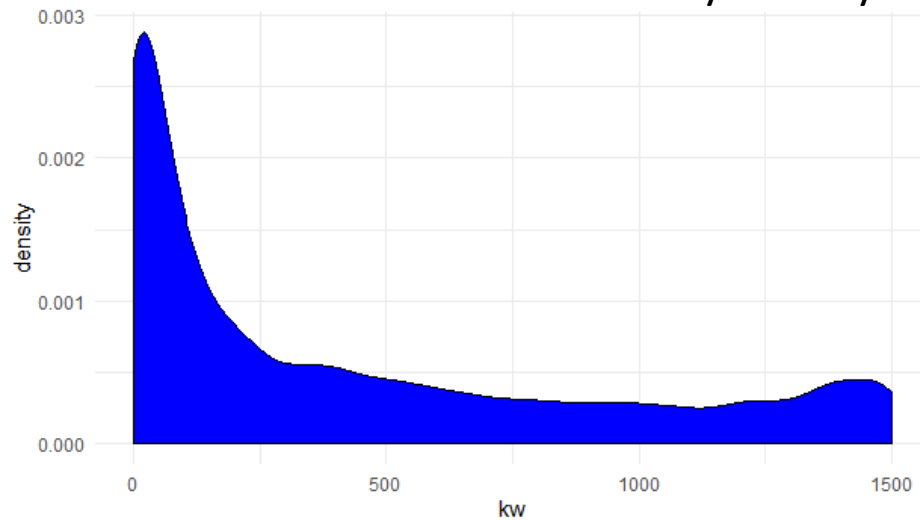


Wind Energy Resources Modeling

Probability density distribution of wind power

Charlotte, NC

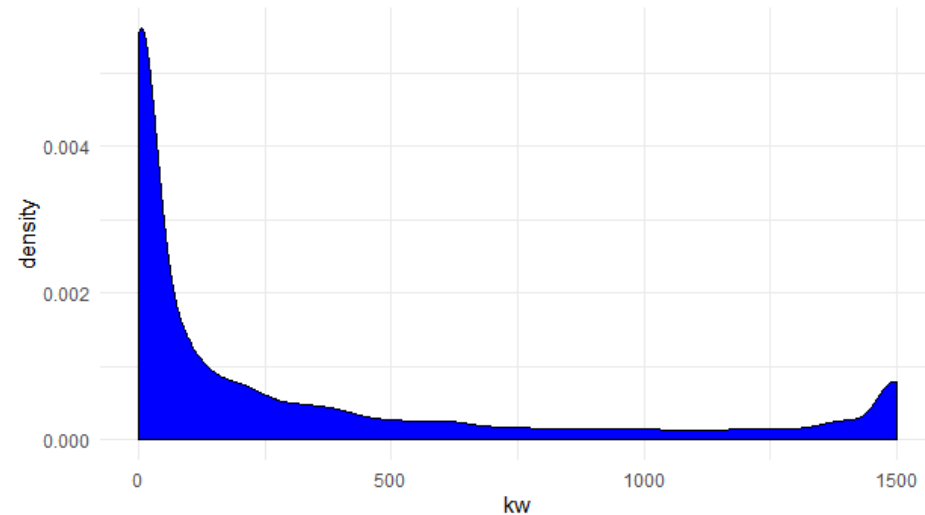
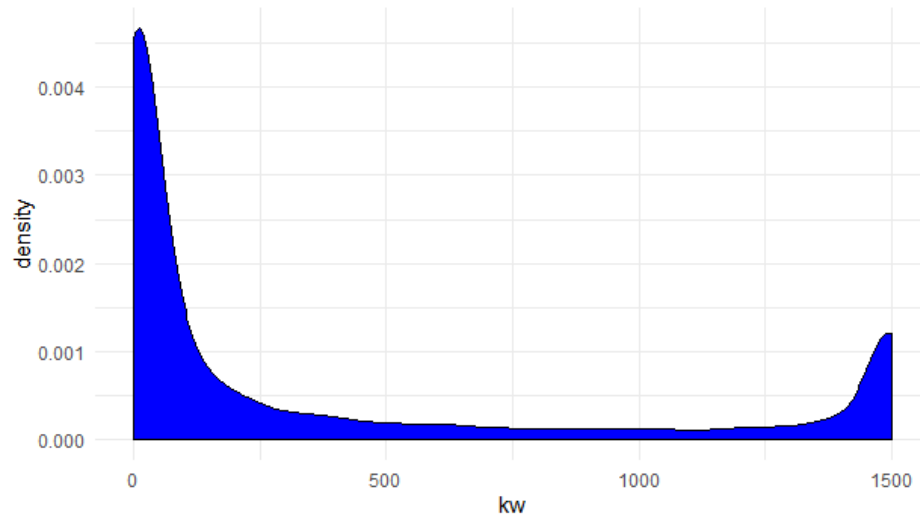
Boston, MA



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

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

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

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

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

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%

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%

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%

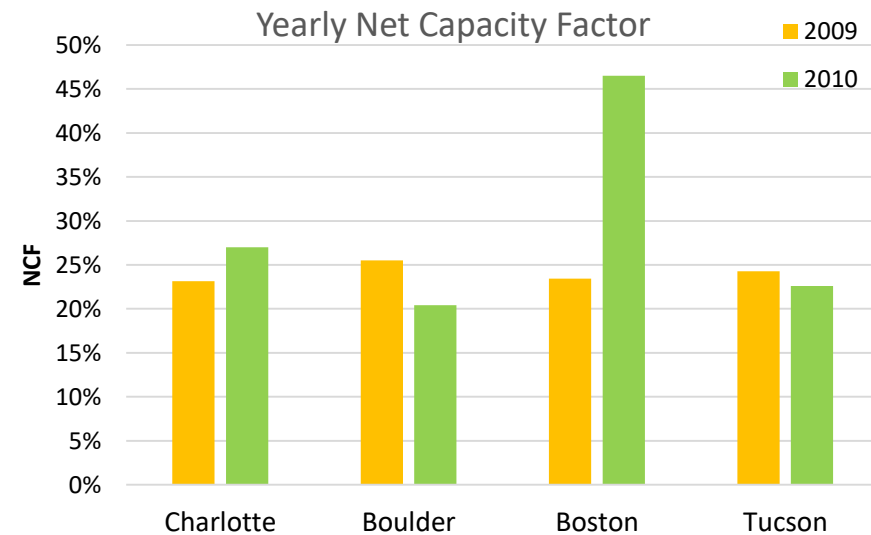
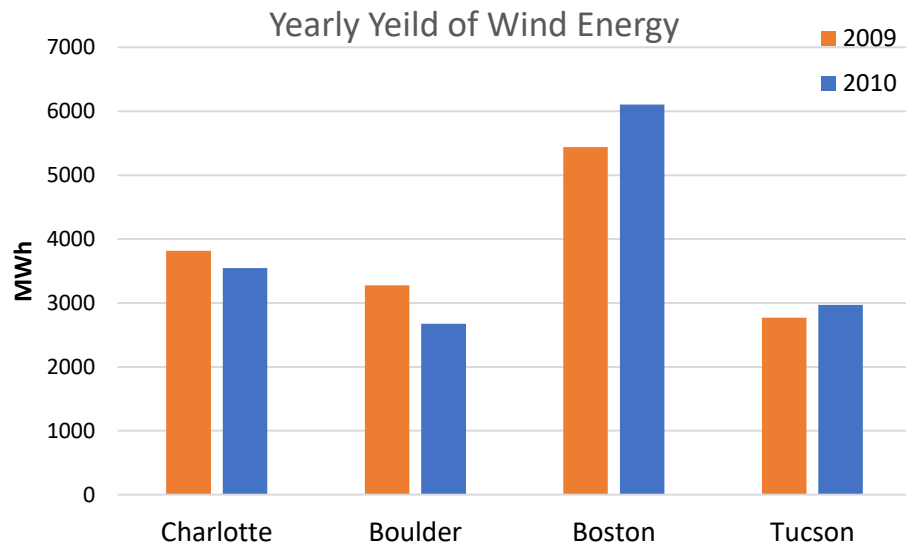
Tucson, AZ

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

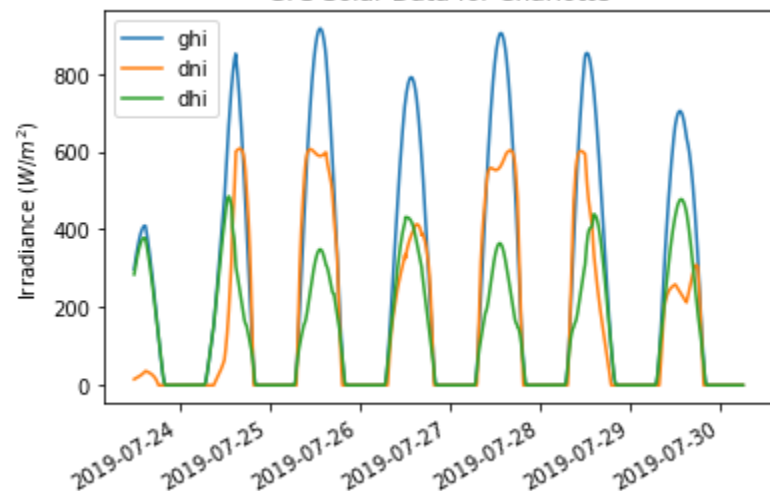
2009	MWh	NCF	2010	MWh	NCF
Charlotte	3818.9	29.1%	Charlotte	3544.6	27.0%
Boulder	3278.4	24.9%	Boulder	2676.9	20.4%
Boston	5440.1	41.4%	Boston	6107.7	46.5%
Tucson	2769.9	21.1%	Tucson	2969.9	22.6%



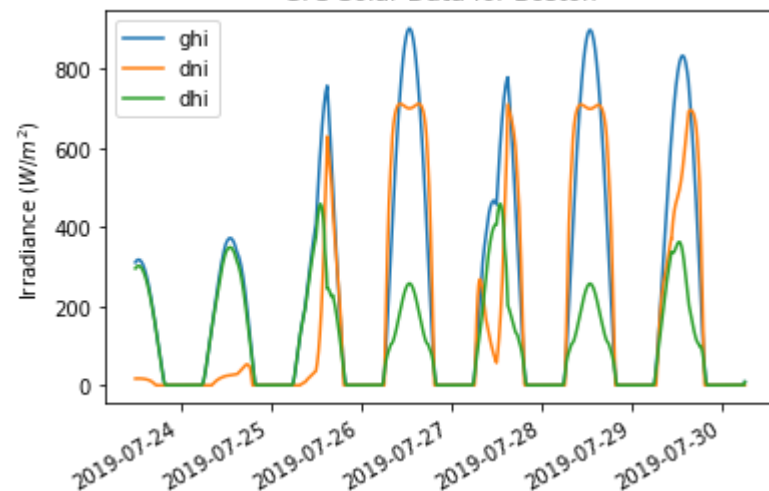
Solar Energy Resources Modeling

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

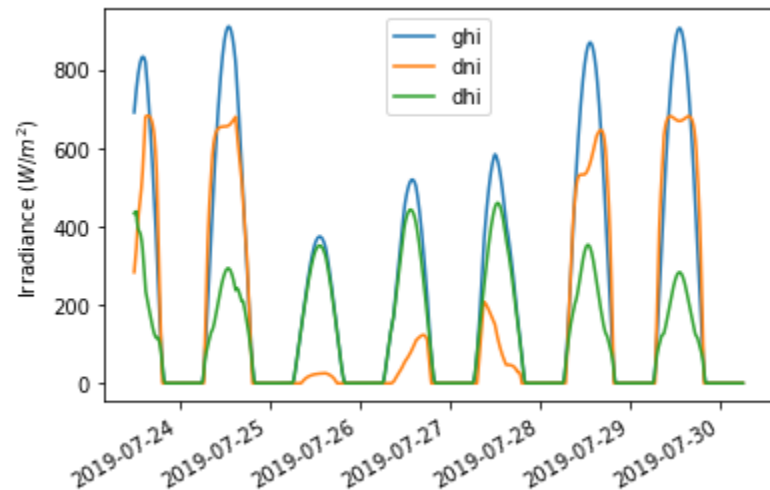
GFS Solar Data for Charlotte



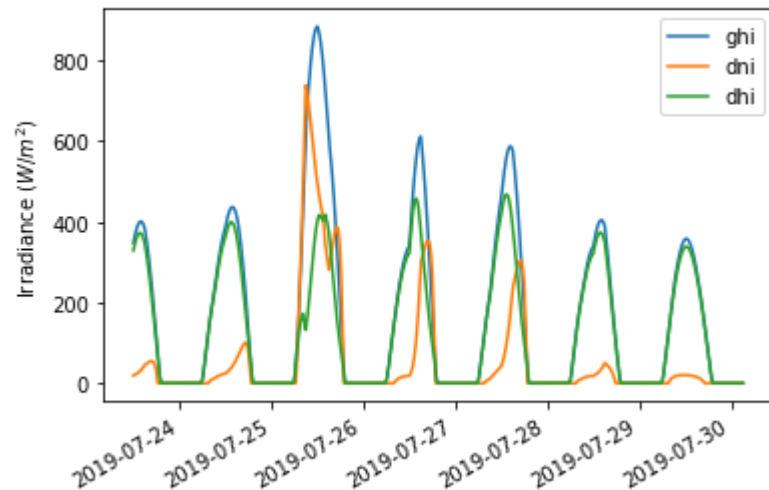
GFS Solar Data for Boston



GFS Solar Data for Boulder

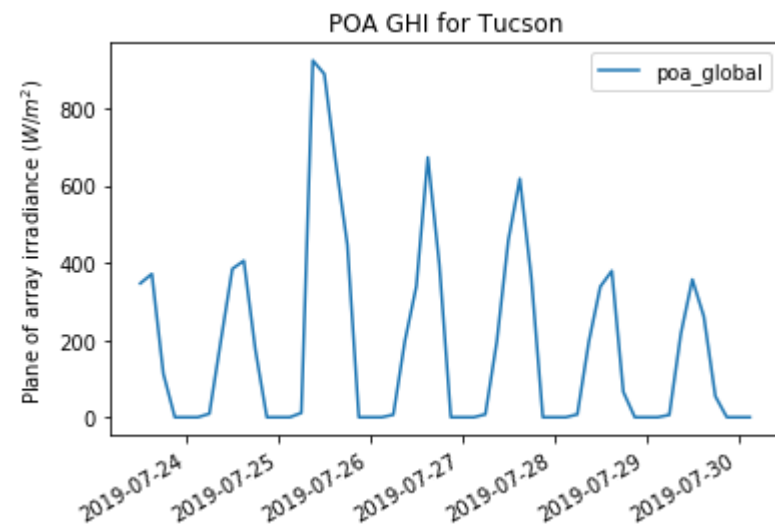
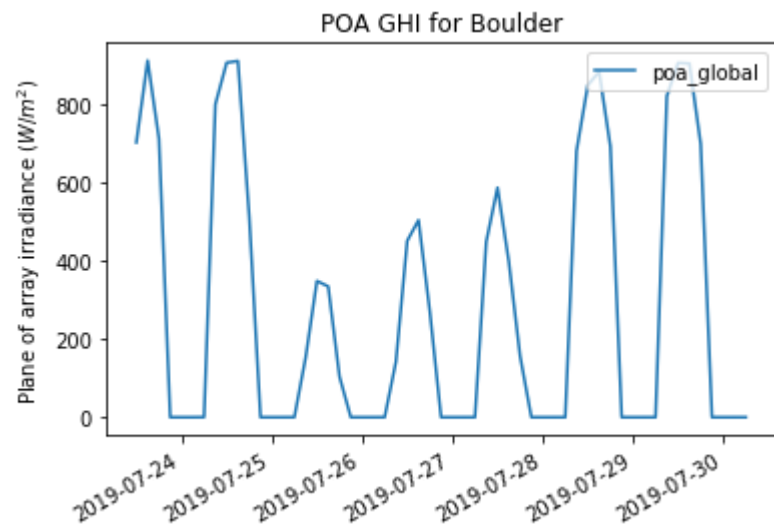
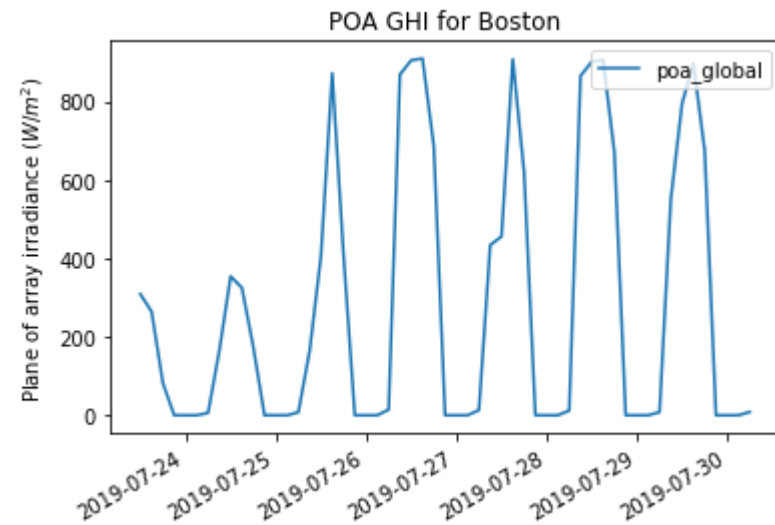
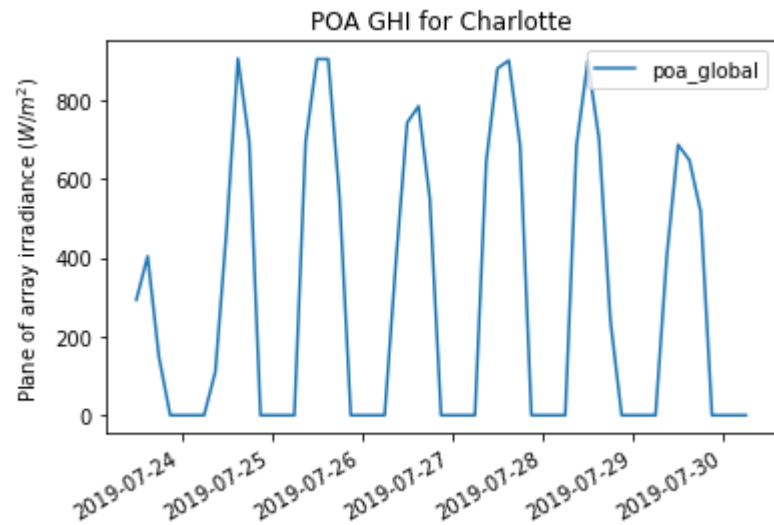


GFS Solar Data for Tucson



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} .

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

PV Module CS5P-220M

Manufacturer: Canadian Solar

Type: Polycrystalline Cells

Power: 220 W (Maximum)

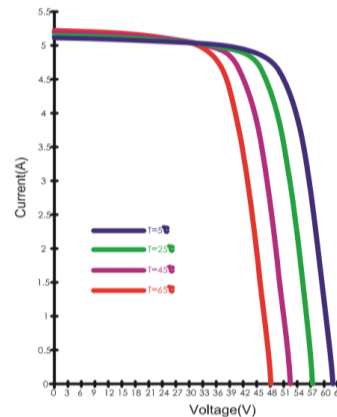
Length: 63.1in (1,602mm)

Width: 41.8in (1,061mm)

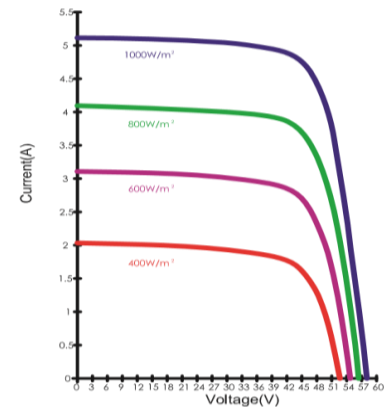
Depth: 1.6in (40mm)

<https://www.solarover.com/panels/cs5p.pdf>

I-V Curves Under Different Temperatures, 1000W/m
CS5P-220



I-V Curves Under Different Irradiances ; AM 1.5 ; 25°C
CS5P-220



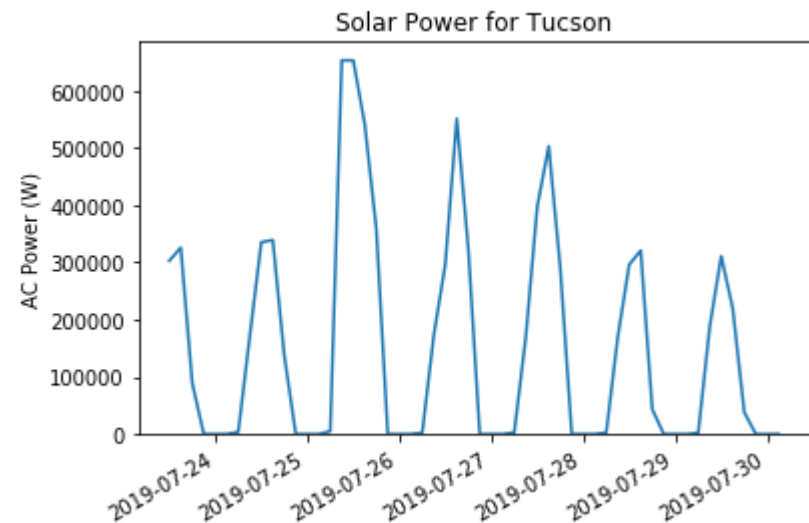
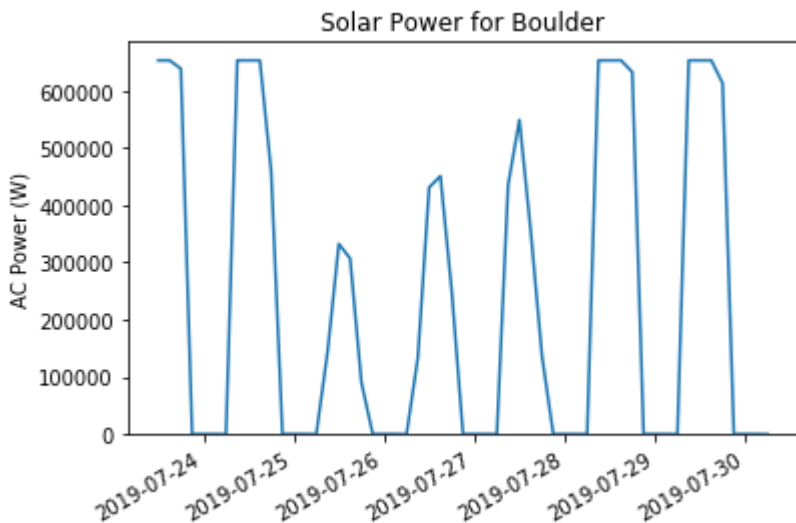
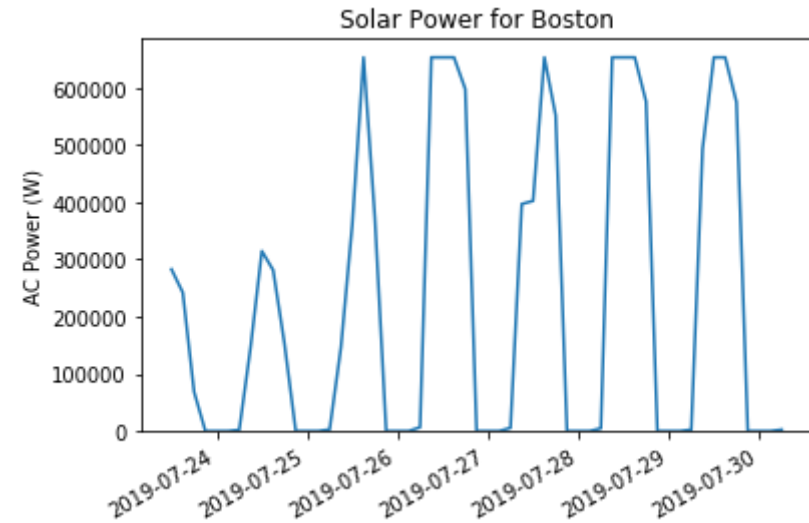
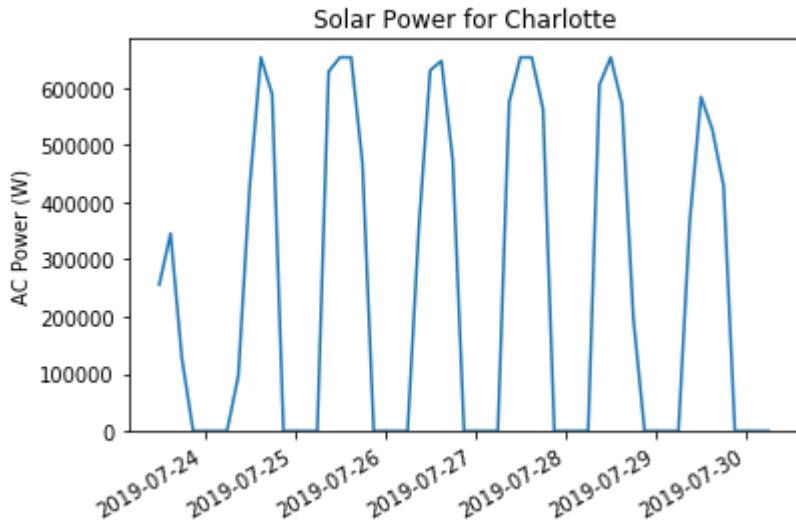
Pvlib Toolbox from Sandia and NREL's SAM package and Weather Data from GFS Global Model

<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

Solar Energy Modeling

Typical Meteorological Year (TMY)

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

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

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

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

Boston, MA

Month0	Wh	NCF
1	20036.95	12.24%
2	24185.77	16.36%
3	28973.17	17.70%
4	30208.65	19.07%
5	34770.35	21.24%
6	32713.24	20.65%
7	35418.34	21.64%
8	33992.69	20.77%
9	29731.42	18.77%
10	25504.76	15.58%
11	19138.34	12.08%
12	17866.74	10.93%

Tucson, AZ

Month0	Wh	NCF
1	32631.67	19.94%
2	31464.61	21.28%
3	38343.02	23.43%
4	41304.64	26.08%
5	41329.6	25.25%
6	38467.5	24.29%
7	35637.61	21.77%
8	36685.47	22.41%
9	36643.06	23.13%
10	38215.38	23.35%
11	35144.2	22.19%
12	32264.5	19.74%

Charlotte, NC

Month	Wh	NCF
1	24215.85	14.79%
2	23356.93	15.80%
3	32597.21	19.92%
4	34440.42	21.74%
5	34155.32	20.87%
6	34034.79	21.49%
7	33878.82	20.70%
8	32241.97	19.70%
9	29538.82	18.65%
10	32026.31	19.57%
11	24730.09	15.61%
12	23873.06	14.60%

Boulder, CO

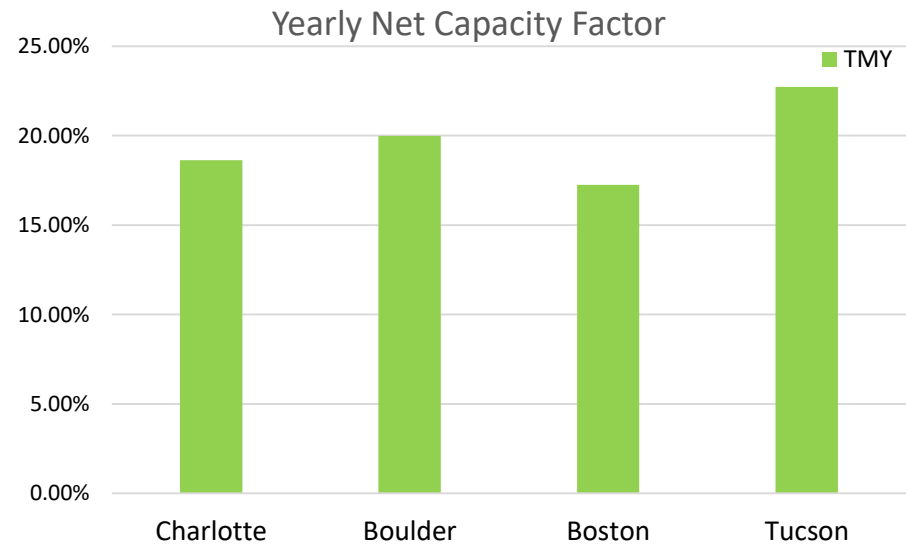
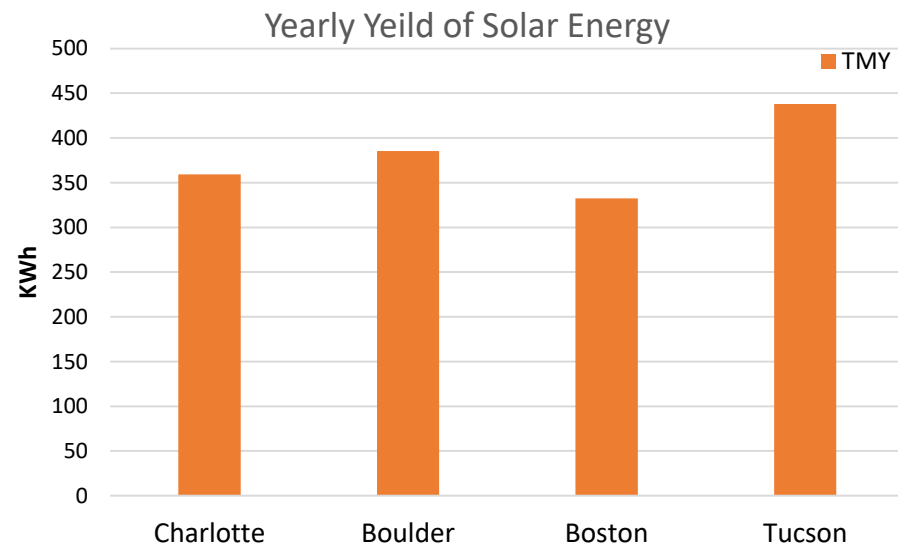
Month	Wh	NCF
1	26432.06	16.15%
2	26847.92	18.16%
3	34451.63	21.05%
4	36840.41	23.26%
5	38157.38	23.31%
6	35819.85	22.61%
7	35061.05	21.42%
8	34979.76	21.37%
9	33776.53	21.32%
10	31482.96	19.23%
11	25915.03	16.36%
12	25576.46	15.65%

Solar Energy Resources Modeling

Calculating the total energy and net capacity factor, as it is done in the wind energy modeling
For 1 PV module (220W, **PV Module CS5P-220M**)

TMY	KWh	NCF
Charlotte	359.0896	18.63%
Boulder	385.341	19.99%
Boston	332.5404	17.26%
Tucson	438.1313	22.73%

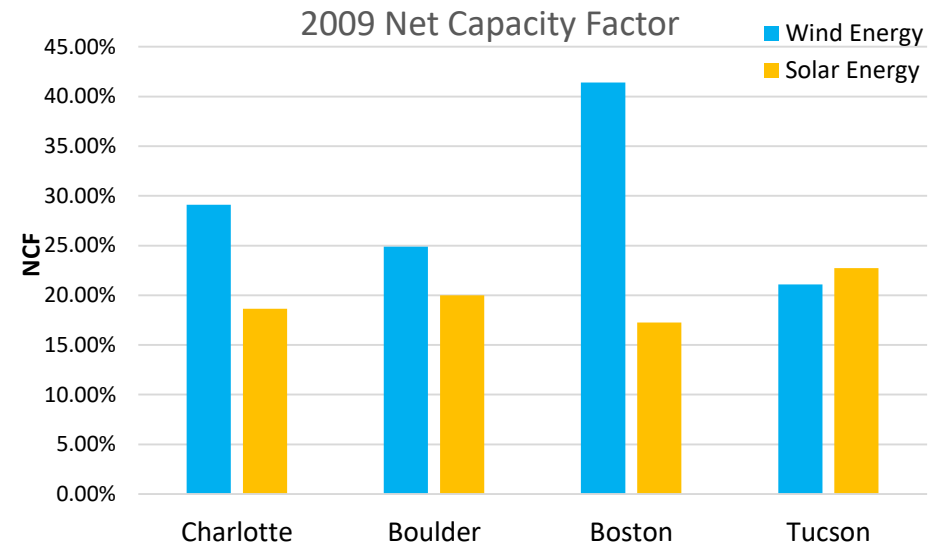
TMY: Typical Meteorological Year, which means it assumes the same variability of solar output for other years.



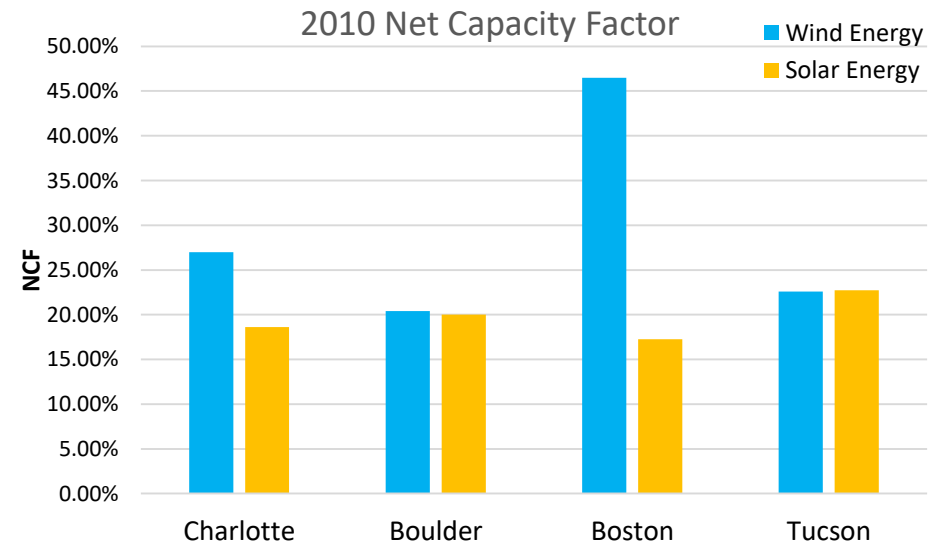
Wind and Solar Energy Resources Modeling

Comparison of NCF for Resources of Wind & Solar Energy

2009	NCF	
	Wind Energy	Solar Energy
Charlotte	29.10%	18.63%
Boulder	24.90%	19.99%
Boston	41.40%	17.26%
Tucson	21.10%	22.73%



2010	NCF	
	Wind Energy	Solar Energy
Charlotte	27.00%	18.63%
Boulder	20.40%	19.99%
Boston	46.50%	17.26%
Tucson	22.60%	22.73%



Wind and Solar Energy Resources Modeling

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

