787: The Impact of Climate Change on Renewable Energy Production across the United States: An Illustrative Study using The Renewable Energy Network Optimization Tool (ReNOT).

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Motivation and Background

As the renewable energy industry continues to grow so does the requirement for atmospheric modeling and analysis tools to maximize both wind and solar power. Renewable energy generation is variable however; presenting challenges for electrical grid operation and planners who are interested in maximizing useable power and minimizing variability and requires a variety of measures to adequately firm power. These measures include the production of non-renewable generation during times when renewable's are not available. One strategy for minimizing the variability of renewable energy production is site diversity.

This site-diversity strategy can be used to mitigate the intermittency in alternative energy production systems while still maximizing saleable energy. The Renewable Energy Network Optimization Tool (ReNOT) has recently been developed to study the merits of site optimization for wind and solar farms. The modeling system has a plug-in architecture that allows us to accommodate a wide variety of renewable energy system designs and performance metrics.

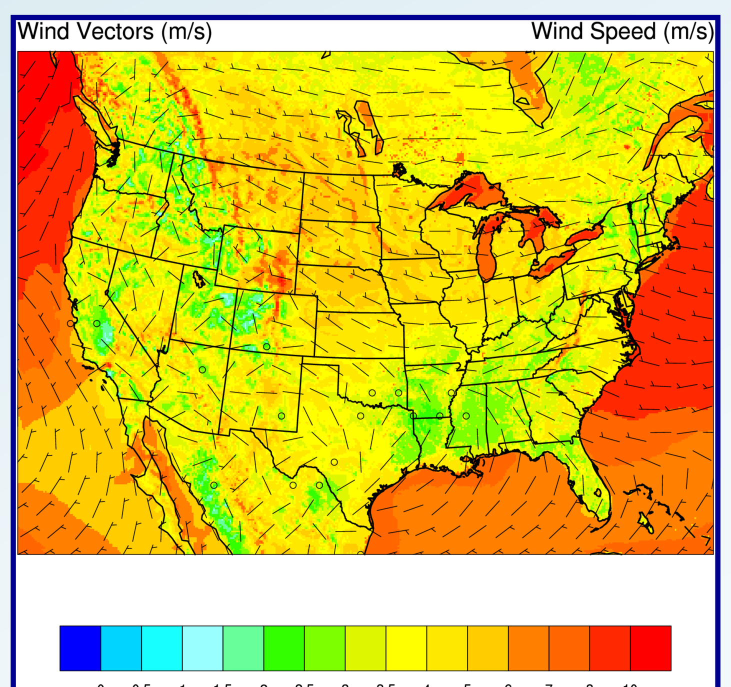
With nearly 35 Gigawatts (GW) of wind generation in existence today across the United States and greatly expanded generation expected over the coming decade it would be of great value to the renewable energy community_to see how climate change impacts might impact the optimal locations of future generation. For example, in this illustrative study we are evaluating marginal increase in wind power generation quantity and consistency across the Continental United States (CONUS) given that the State of Texas today has approximately 9.4 GW of installed "name-plate" capacity. This study is performed using our 15 year (1995-2009) downscale simulation of hub-height winds over CONUS at 12 km and 1 hour resolution, respectively. In addition, we have developed a climate change projection of hub-height winds for the period 2060-2070. This will allow an impact study to investigate whether the best generation locations change from the present (1995-2009) compared to the future. The question is given the current production today over Texas where might generation capacity be sited over the remainder of CONUS to even out the actual electrical production, and do the regions of the best marginal increase in generation migrate given climate change.

Objectives

1. Given there is ~8.35 GW of nameplate capacity in Texas today, estimate, locations with the best marginal increase in useable power over the period 1995-2009.
2. Repeat this study for the period 2060-2070 to estimate the change in marginal benefits and to judge the extent that climate changes the spatial distribution of winds.

Wind data used in study

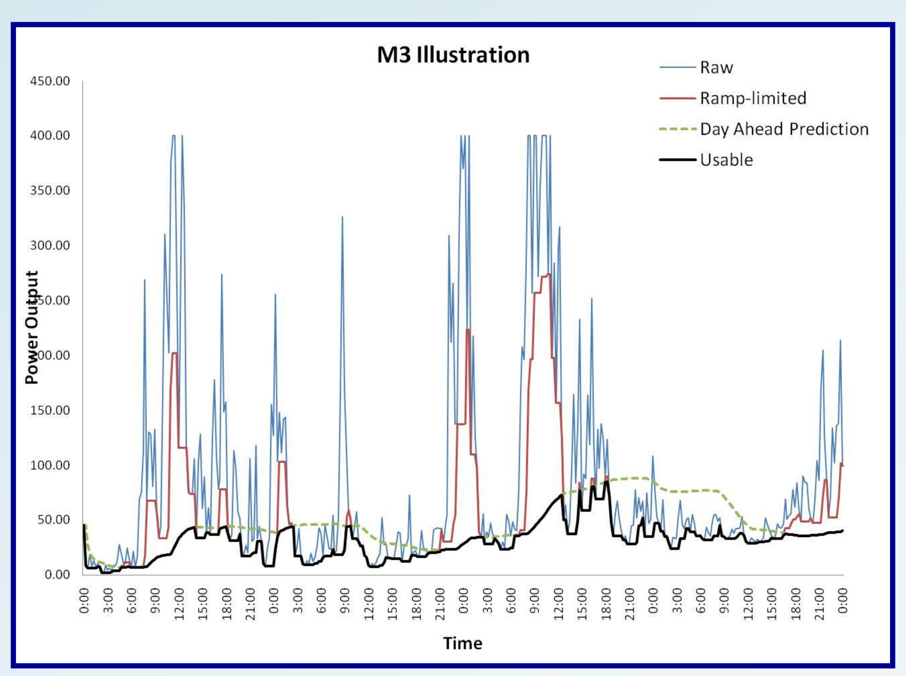
The Weather Research and Forecasting (WRF) mesoscale model is applied to generate high-resolution wind databases to support the site selection of wind farms. These databases are generated on High Performance Computing systems such as the Rocky Mountain Supercomputing Center (RMSC). WRF is a high resolution, limited area, non-hydrostatic model. We successfully performed decadal simulations with WRF, running in climate mode, for current and future periods over CONUS. We utilized a number of features implemented in the WRF model that allow realistic representation of the climate system in long-term simulations, e.g. variable CO_2 concentrations, diurnal variations of the skin Sea Surface Temperature (SST), deep soil temperature and SST updates. The NCEP reanalysis and the ECHAM5/MPI-OM General Circulation Model (GCM) are used as the forcing model which provide the necessary initial and boundary conditions. For the present climate (1995- 2009), WRF was forced with NCEP reanalysis data. For the 21th century climate (2060-2069), we used an ECHAM5 simulation with the Special Report on Emissions (SRES) A1B emissions scenario. WRF was run in nested mode at spatial resolution of 108 km, 36 km and 12 km and 28 vertical levels. The wind speed at approximately 40 meters height (hub-height for most wind turbines) is saved every hour. In this study the Single-moment 5-class (WSM5) microphysics scheme and the Kain-Fritsch convective parameterization scheme is utilized. The Noah Land Surface Model and Yonsei University (YSU) Planetary Boundary Layer scheme are used. Shortwave and longwave radiation are computed with the CAM SW and LW scheme. Comparisons of model output are made to data collected from a wind farm in Montana and show correlations around 0.7.



Climatology of Winds over CONUS (Jan 2001)

Modeling Concepts

- Since we are interested in stable power that has minimal variability we require an appropriate scoring metric
- We define a metric called Useable Power which factors in short-term variability and ability to predict
- Locations with low variability and high predictability will have a larger Useable Power
- Usable Power (M3) = Raw Power – {*short-term variability (STV)* and *prediction*}
- *STV* represents an approximation to the excess power that can not be sold on market because it is unreliable
- Prediction reflects the ability to forecast tomorrow's power generation
- Our approximation of these two factors is:
  - Accounting for STV (1 hour) by choosing the minimum amount of power over that period
  - Evaluating the previous day's mean power with no credit for power greater than the mean



The running minimum network sum-power over a trailing time window (K+1 steps wide).

$$R_j^K = \min_{k=0,K}\{P_{j-k}\}$$

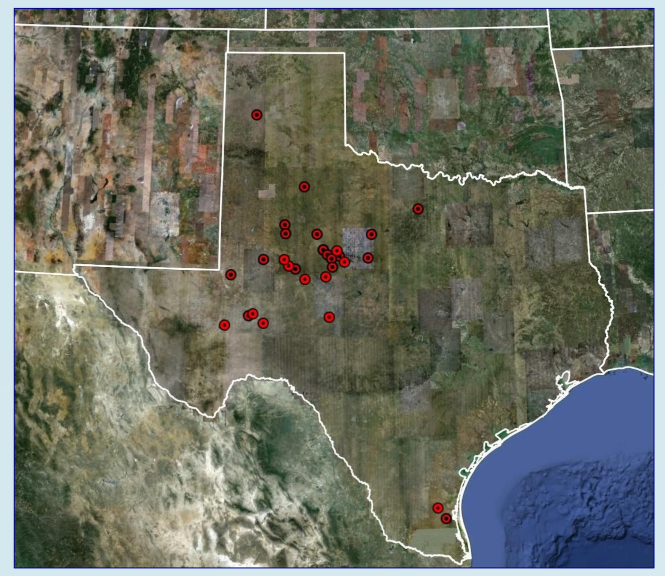
The trailing H-step mean of the running K-step trailing minimum. This will be a proxy for a day-ahead forecast with H set to enough time-steps to cover 24 hours (In principal, this could be set to any time length).

$$\overline{R}_j^{H,K} = \frac{1}{H}\sum_{k=1}^{H} R_{j-k}^K$$

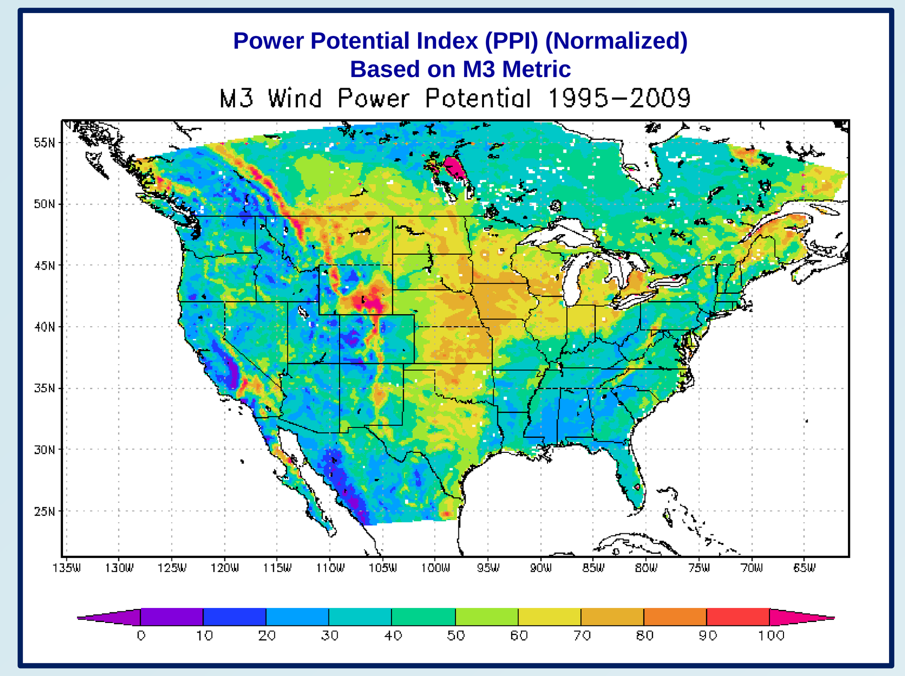
The M3 metric caps utility at no more than the previous day's average power, and accounts for time-to-time variability over a shorter window. Networks that consistently produce power from day to day and time to time will be favored.

$$M3 = \frac{1}{T}\sum_{j=1}^{T} \min\left(R_j^K, \overline{R}_j^{H,K}\right)$$

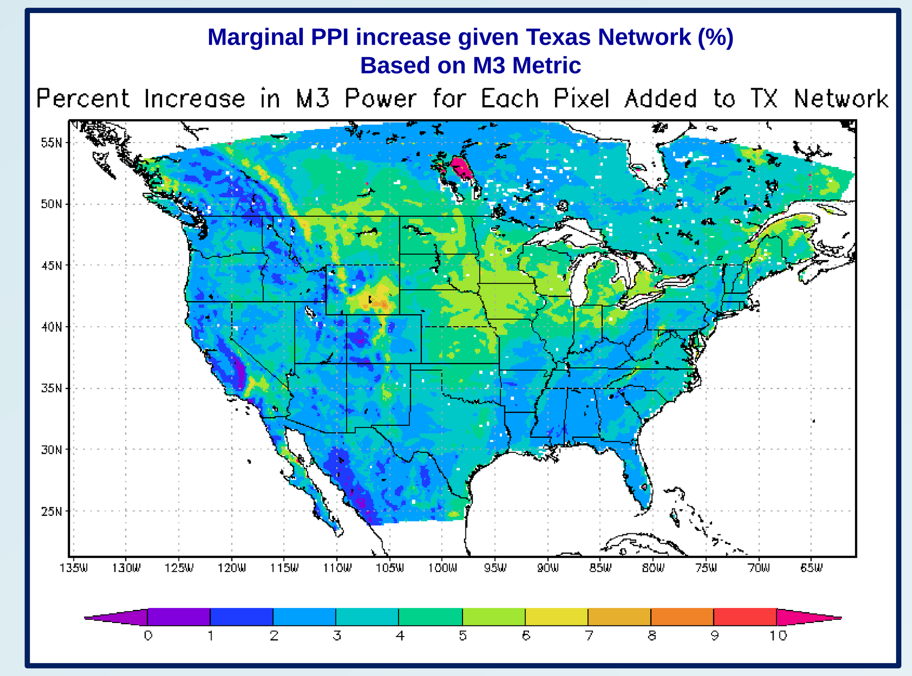
The impact of climate change on wind resourcing in the United States based on a comparison between the period 2060-2069 and 1995-2009.



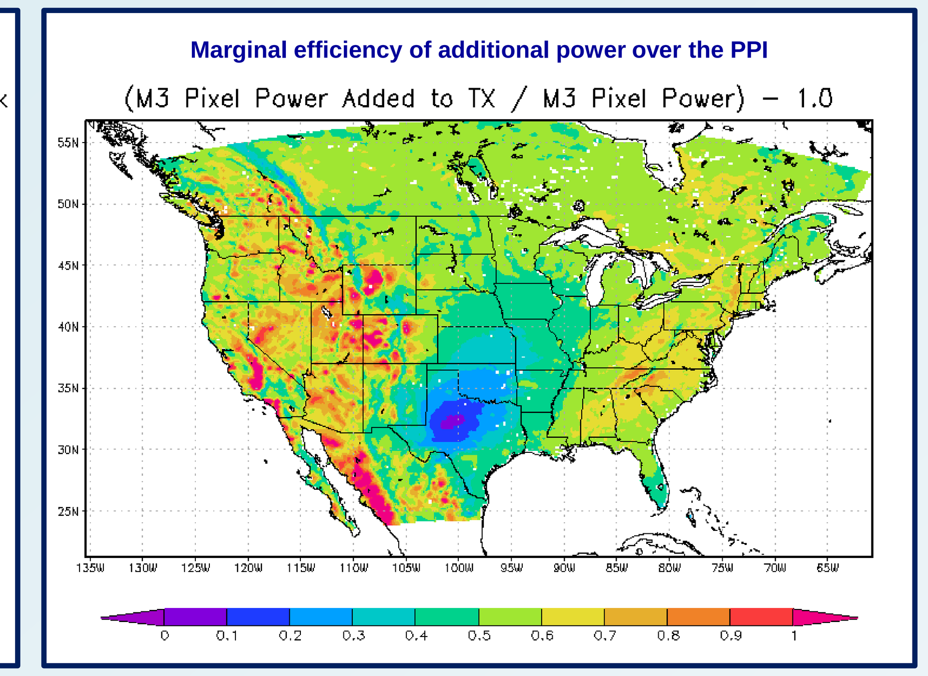
Step 1: Identify all the wind farm locations in Texas with a name plate capacity greater than 120 MW. There are thirty-one.
Total Capacity = 8.35 GW



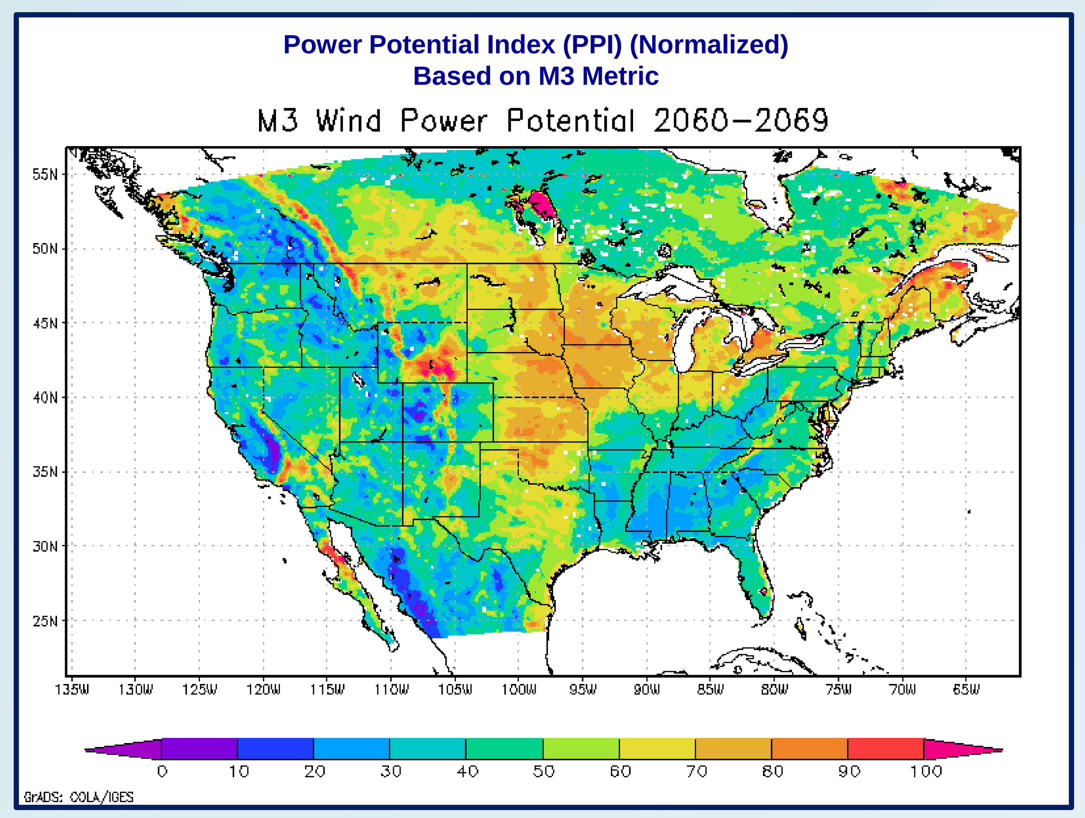
The Power Potential for each 12km pixel in CONUS based on the M3 Metric of useable power. Brighter shaded areas indicate good wind resources.

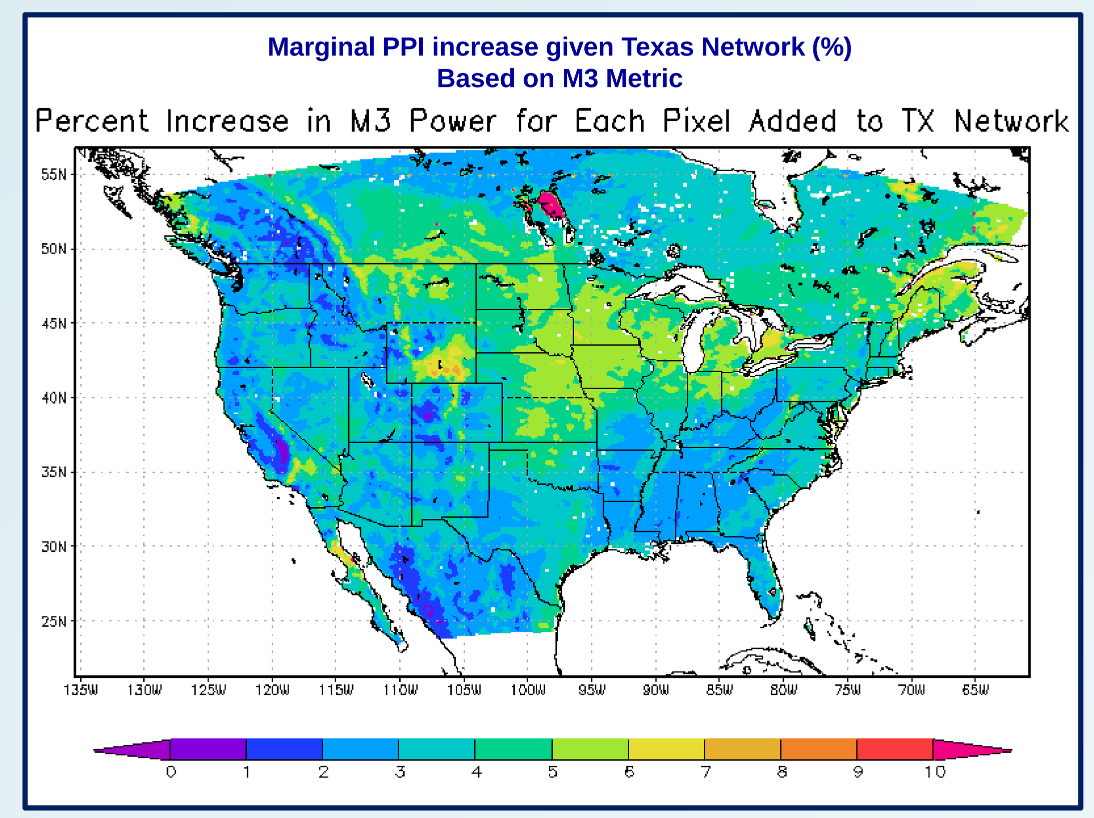


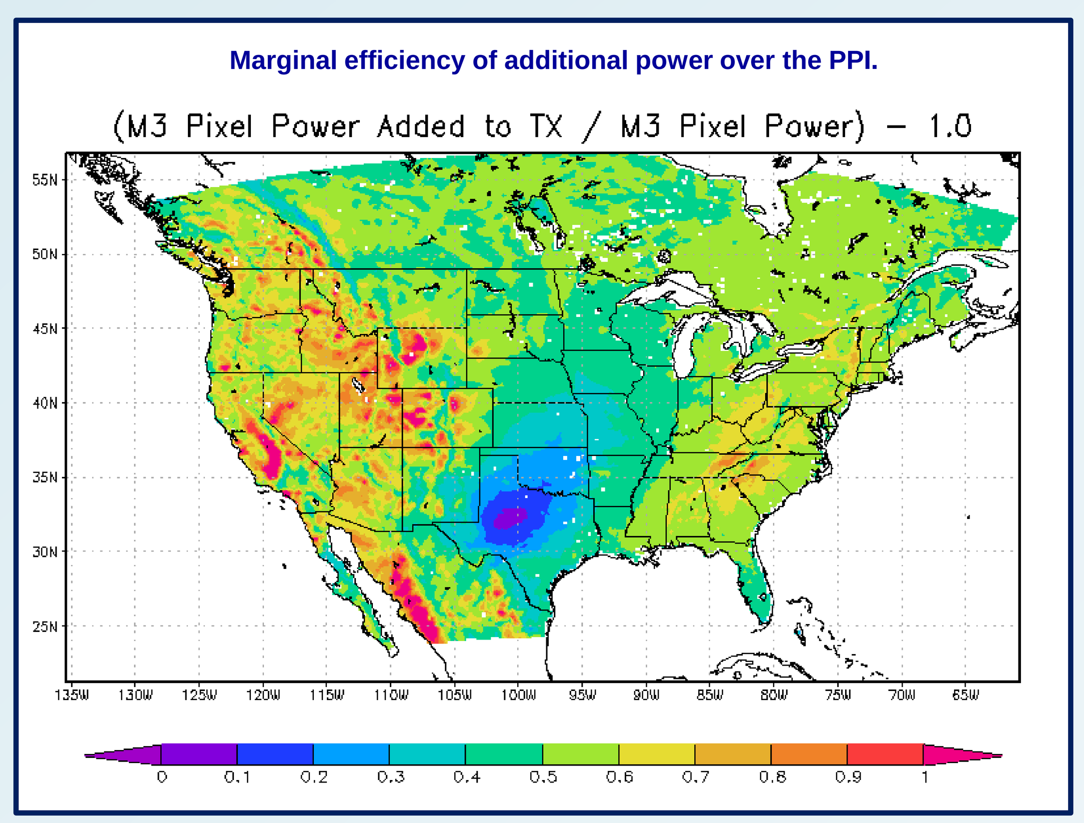
Brighter shaded areas indicate where marginal power potential exists relative to the 8.35GW of power being generated in Texas. Areas in the Northern Plains and Southeast Wyoming provide complimentary power.

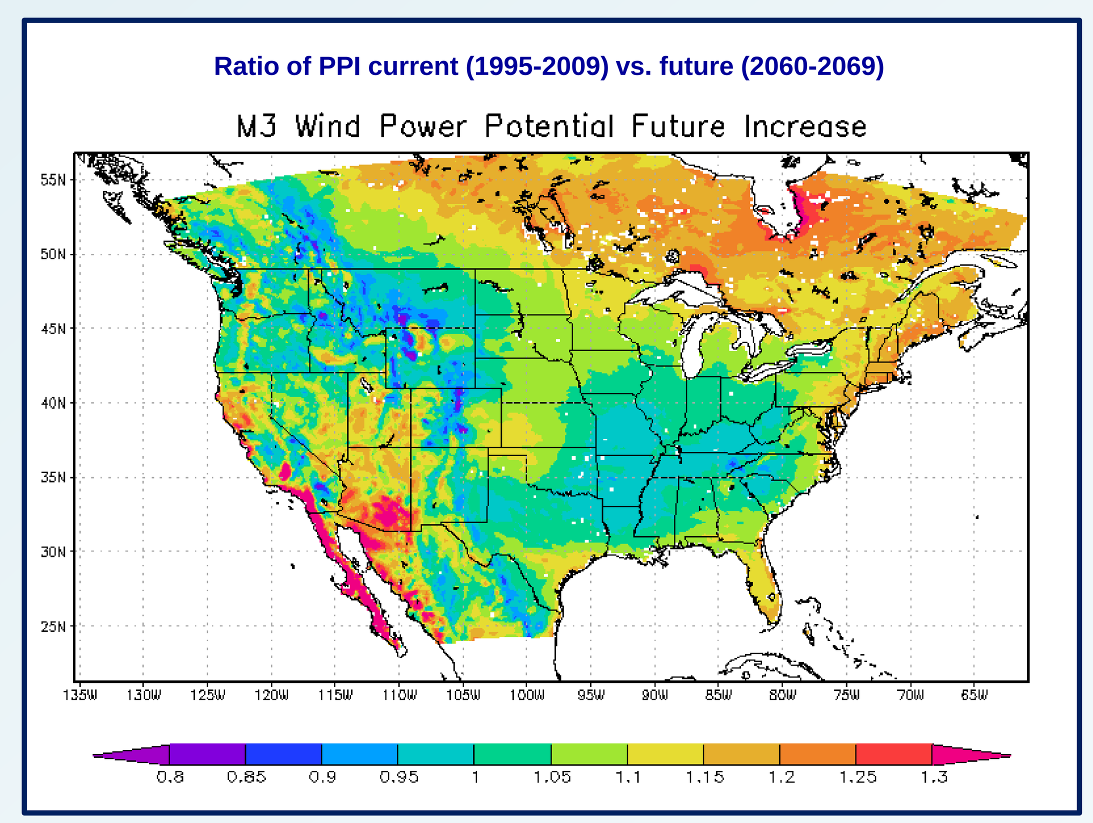


Brighter shaded areas indicate where additional capacity can be found. There is little benefit of adding additional capacity in Texas relative to areas in the West and Southeast United States based on the M3 Metric of Useable Power.









Results indicate that the spatial distribution of winds between the current period (1995-2009) and the future (2060-2069) change very little. The marginal efficiency of additional power given existing power capacity of Texas does not change much from the current to the future. Changes on the order of +/-5-10% are observed depending on location in the Continental United States. The ratio of PPI of future climate to current climate indicates areas in Southern and Eastern Canada and the Northeastern United States show an increase. Increases are also observed in the Desert Southwest.

One caveat. The future run has not yet been bias corrected with a free run of the WRF/ECHAM for the current period, therefore, these results are more illustrative then quantitative.

Summary

- The Renewable Energy Network Optimization Tool (ReNOT) has been developed to assist in the optimal placement of networks of wind and/or solar farms
- An estimate of useable power is generated in order to take in effects of short-term wind variability and predictability of wind at a given site.
- ReNOT shows how geographical diversity benefits the build out of wind power in areas that may not be commonly thought of as windy.
- The spatial distribution of winds do not appear to change much when a simulation of a future climate is analyzed.