

# Does the continental United States have the weather to support large-scale wind and solar deployment?

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# Study Description

- **Motivation:** Wind and solar energy generation systems do not work well over small geographic regions because (1) many places have poor wind and solar resources, and (2) wind and solar at a given location are highly correlated to nearby locations
- Over a large enough area, wind and solar power are likely to be available somewhere in the domain. **How big must a geographic area be to provide reliable wind and solar energy?**
- **Solution:** Use a mathematical “optimization” to determine how a combined “wind, solar, and gas” energy system would vary with geographic scale.
- We used hourly wind and solar weather data on a 13 km grid and actual US hourly demand from 2007 projected to 2030.
- Similar to today, when demand (load) exceeds national generation, use natural gas power to meet load.



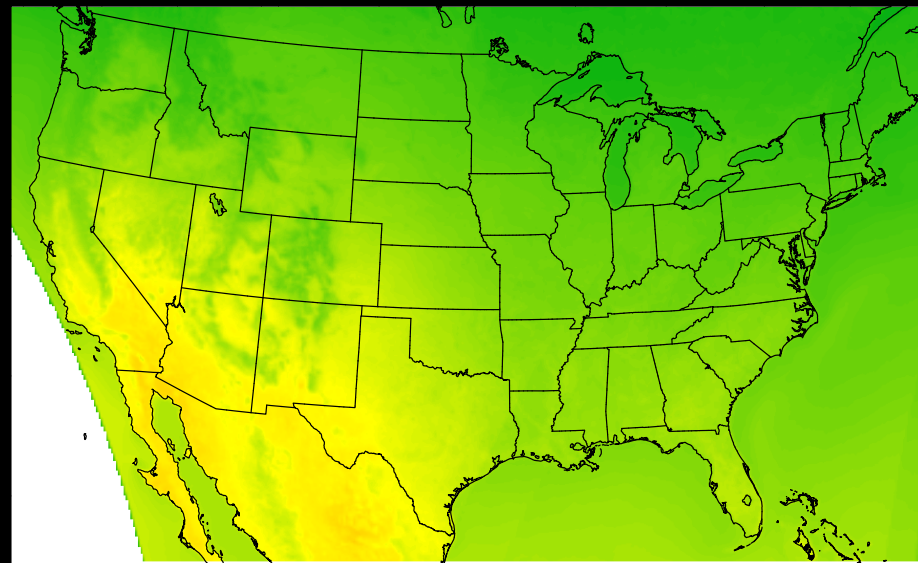
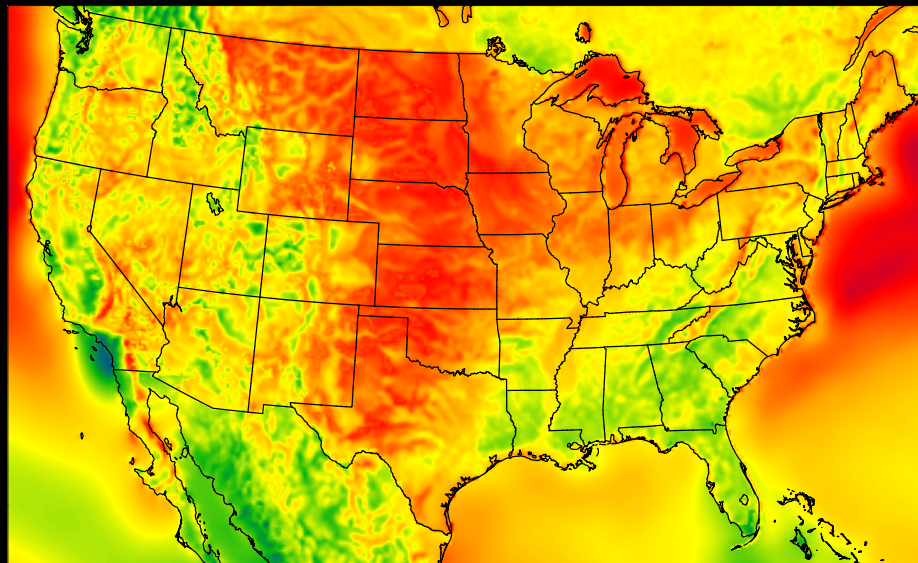
# Electrical Load





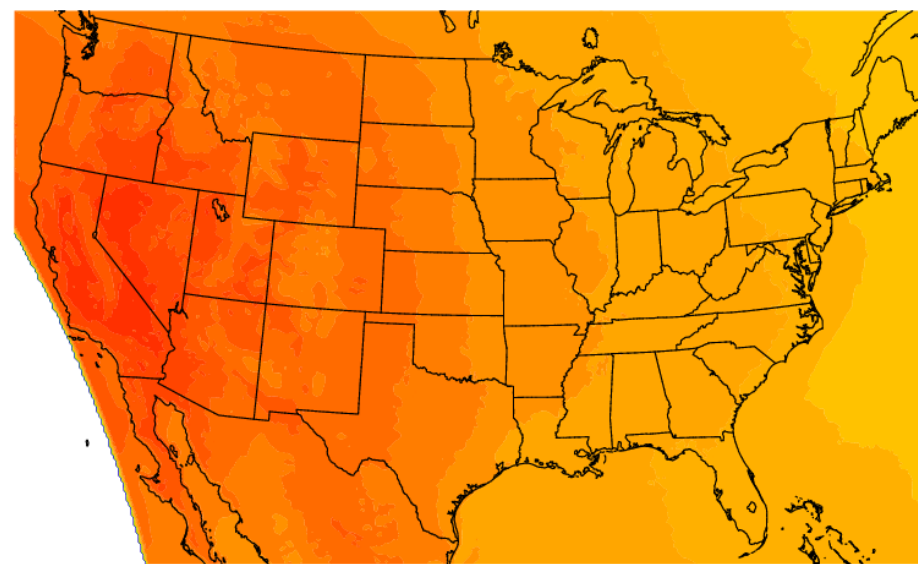
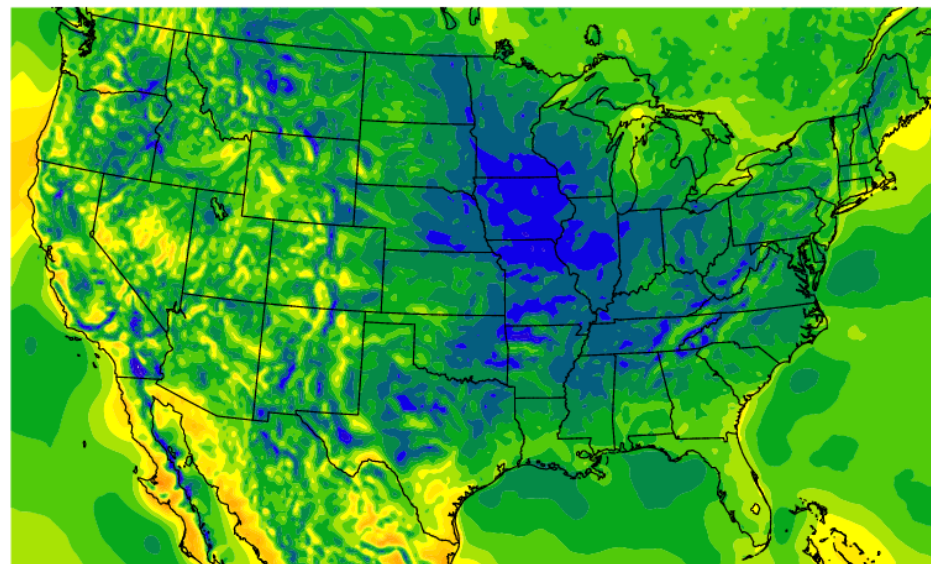
Average wind Capacity factor 2006-2008

Average solar Capacity factor 2006-2008



Wind Covariance divided by Average Load

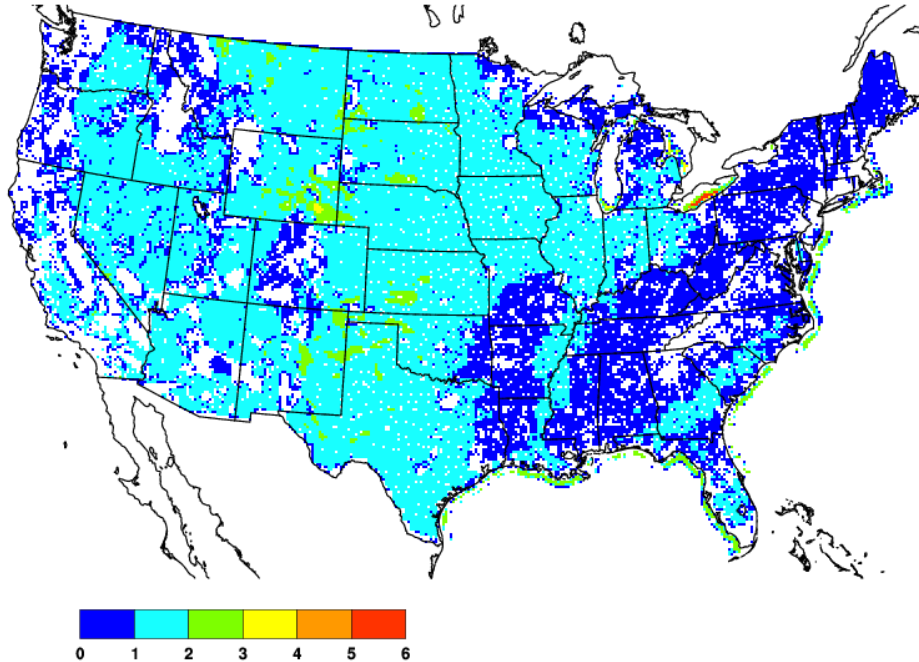
Utility Covariance divided by Average Load



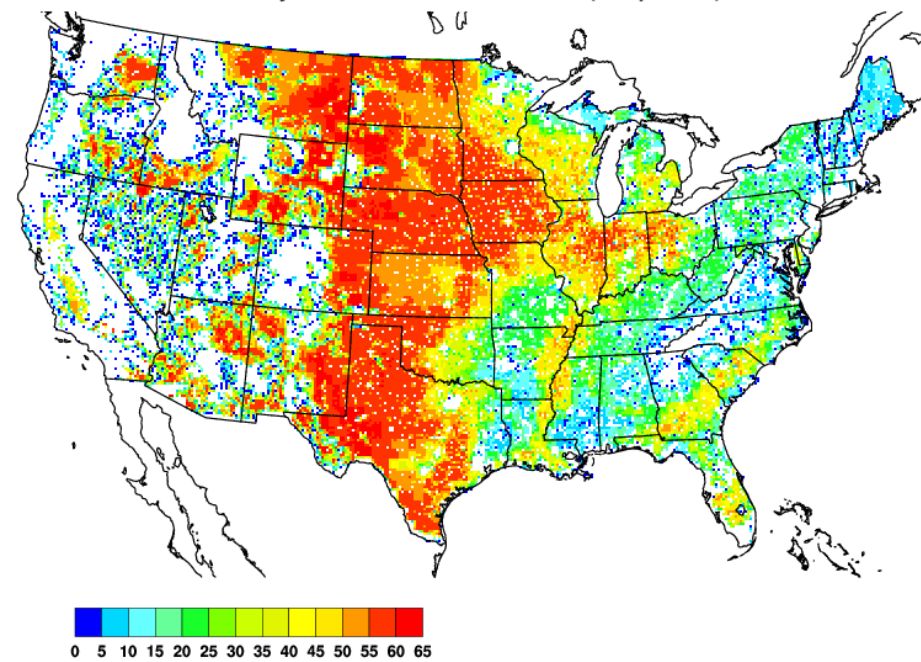


# Classification Maps

Wind Turbines Allowed Per RUC Box (MW per km<sup>2</sup>)



PV Utility Plants Allowed Per RUC Box (MW per km<sup>2</sup>)



- The type and amount of electricity generation installed in each RUC cell is constrained by:
  - Spacing between facilities
  - Topography of the land
  - Land Use (residential, commercial, protected lands, etc...)



# Price Parameter Space

- Costs parameter space:

TECHNOLOGY	LOW	MID	HIGH
ONSHORE WIND	\$1.61 / W	\$2.26 / W	\$2.89 / W
OFFSHORE WIND	\$3.88 / W	\$5.43 / W	\$6.98 / W
PHOTOVOLTAICS	\$1.10 / W	\$2.02 / W	\$2.94 / W
CORRESPONDING NATURAL GAS	\$8.63 / mmBtu	\$6.60 / mmBtu	\$4.56 / mmBtu

- Capital costs are amortized for the life of the technology.
- Natural gas capital is \$1.00 / W.
- Transmission costs are \$ 1306.00 / MW-mile.
- RE Generation costs obtained from DOE EERE Transparent Cost Database



# Transmission Proxy

- The network of wind and solar plants supplemented with natural gas is found simultaneous with a transmission network. The optimization calculates the least-cost solution for the combined system.





# The Minimization Procedure

Minimize:



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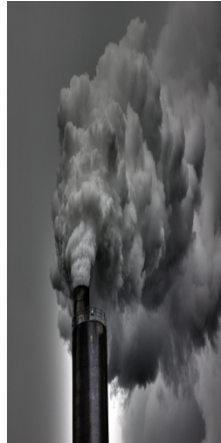
Subject to:



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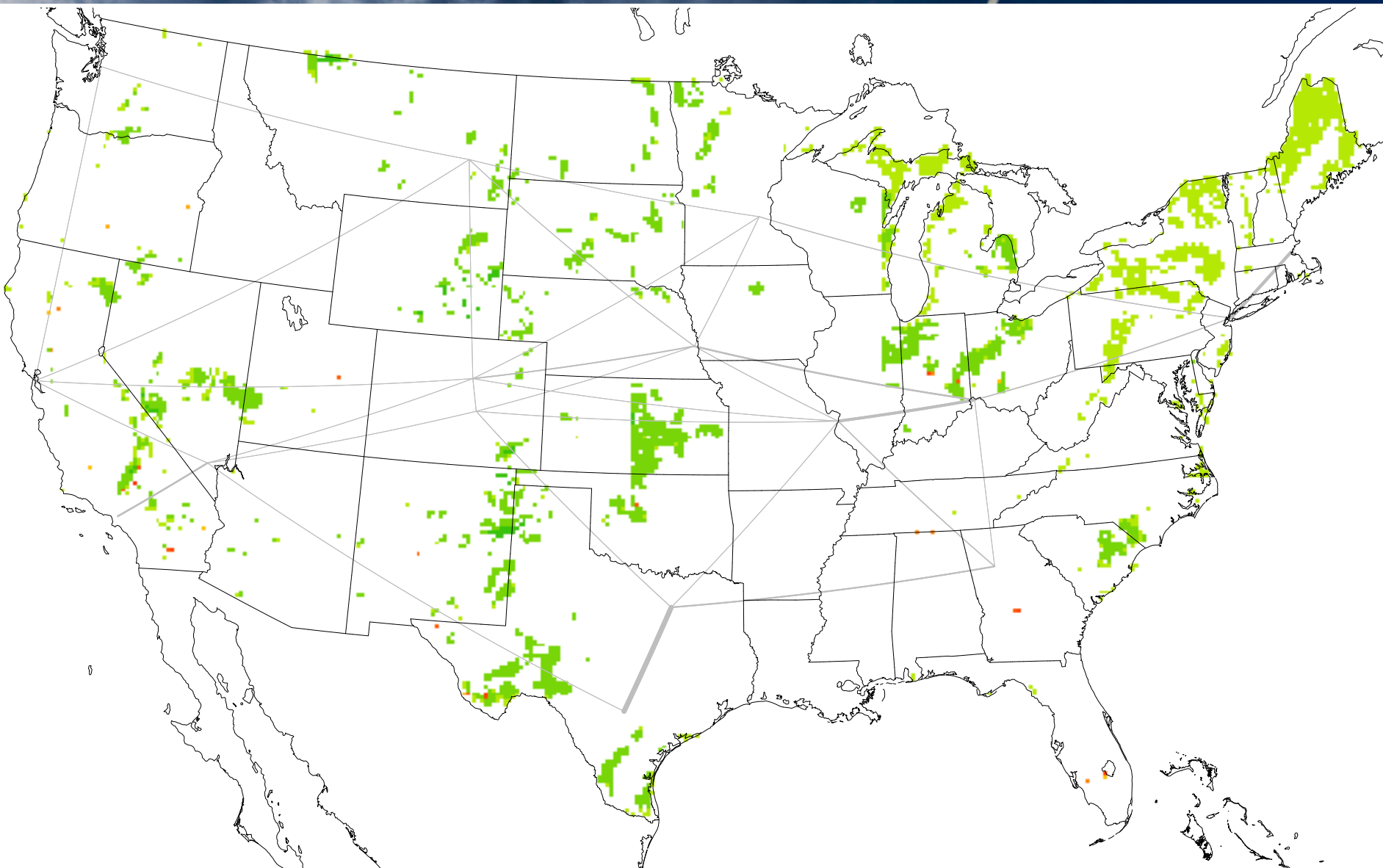
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ALL OTHER EQUATIONS CONSTRAIN THE MAGNITUDE OF ANY OF THE TERMS



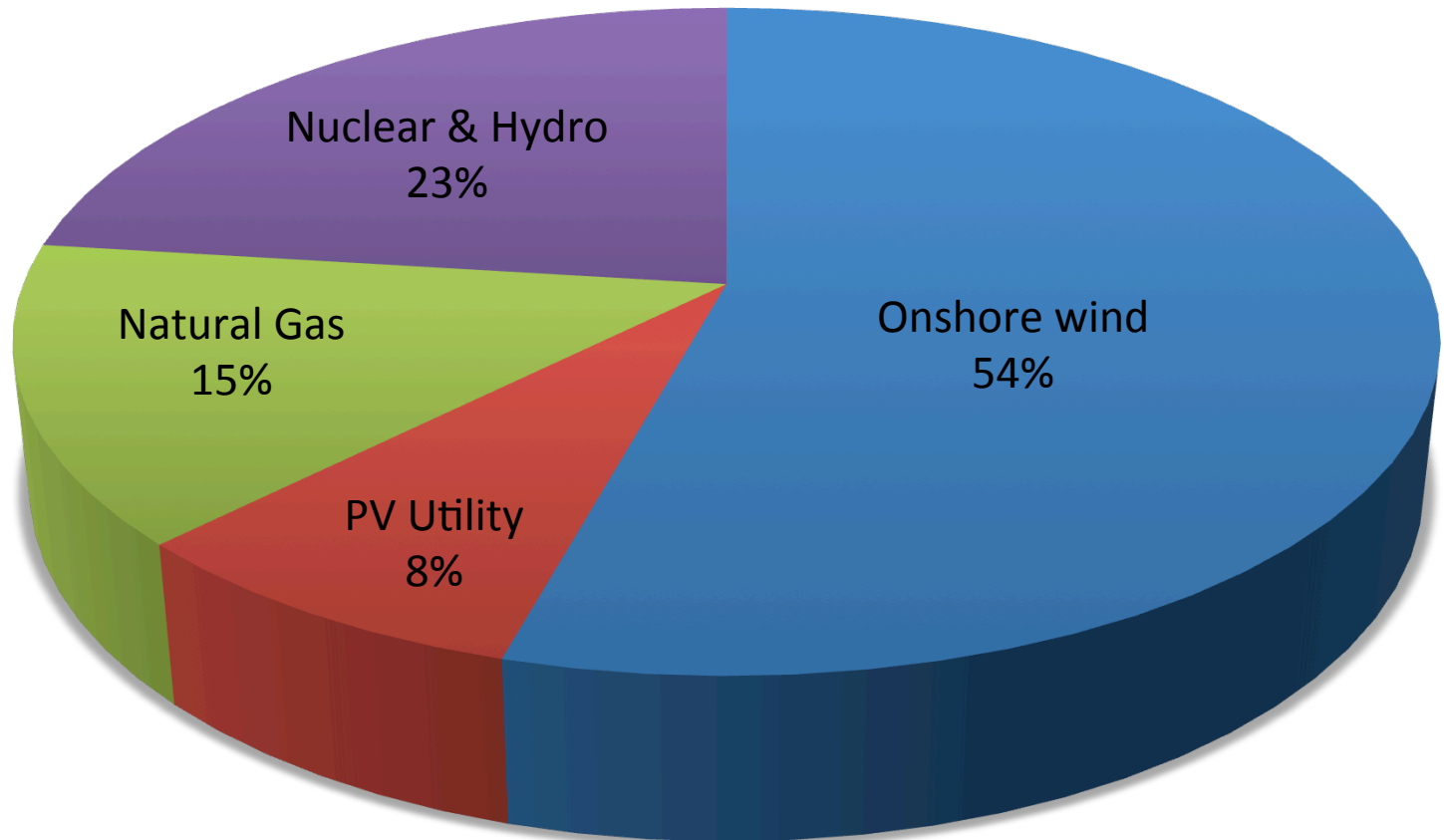
# Full CONUS Solution



0 1 2 3 4 5 0 1 2 3 4 5 0 10 20 30 40 50 60 70

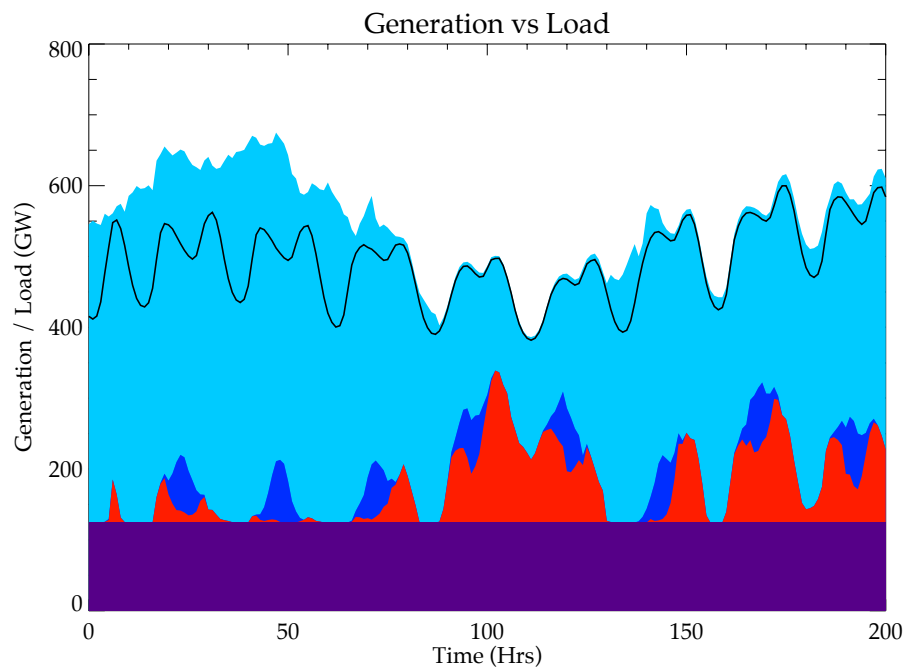


# Electricity Production (%) by source

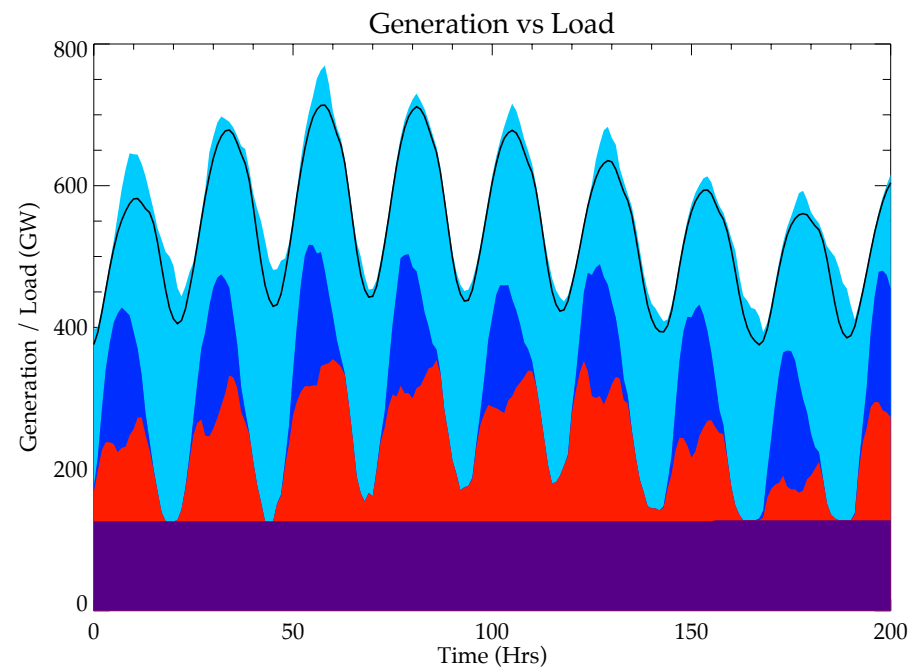




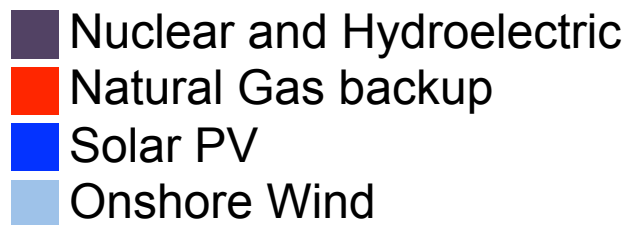
# Sample Electric Load Curves



WINTER

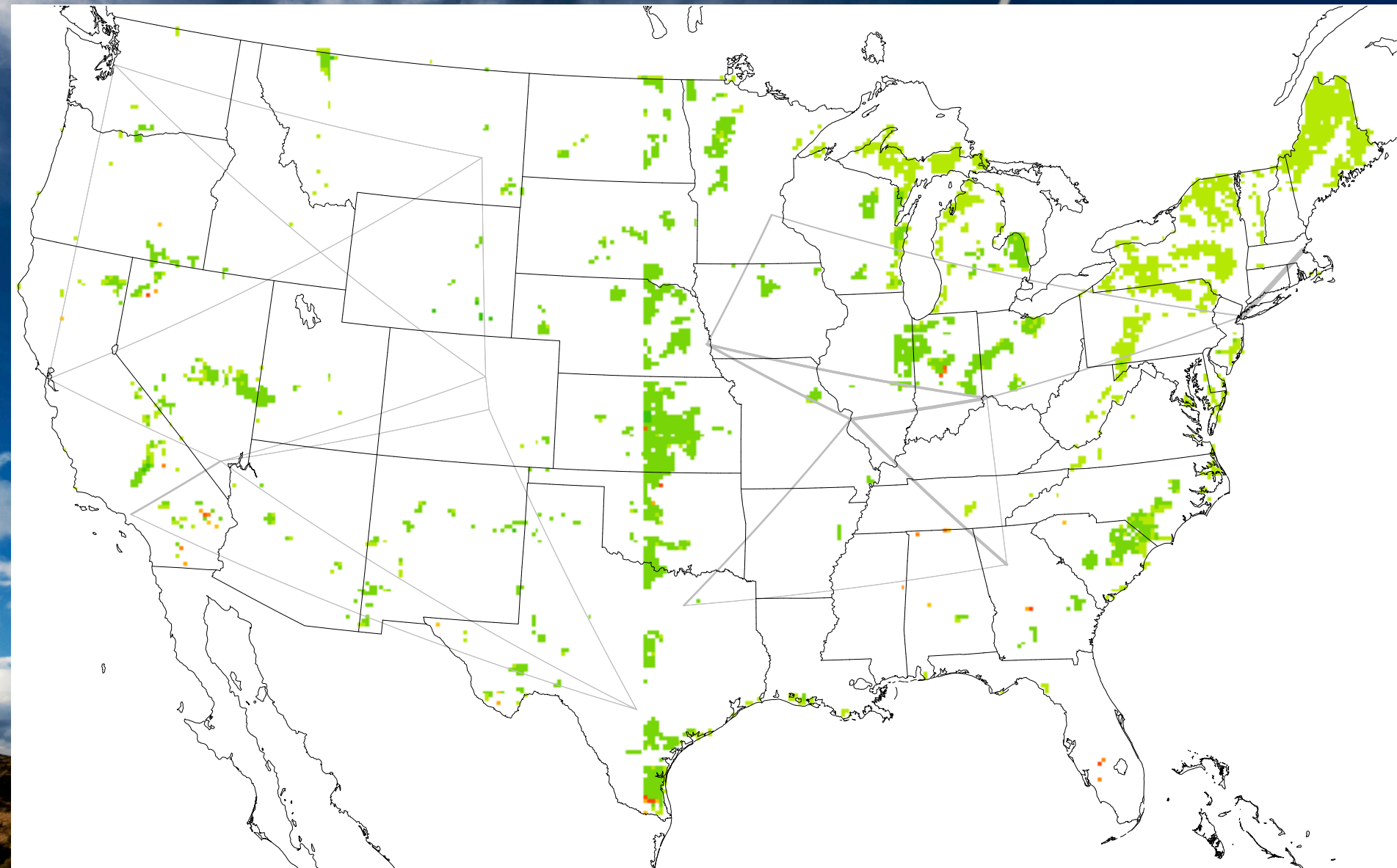


SUMMER





# Half CONUS Solution



0 1 2 3 4 5

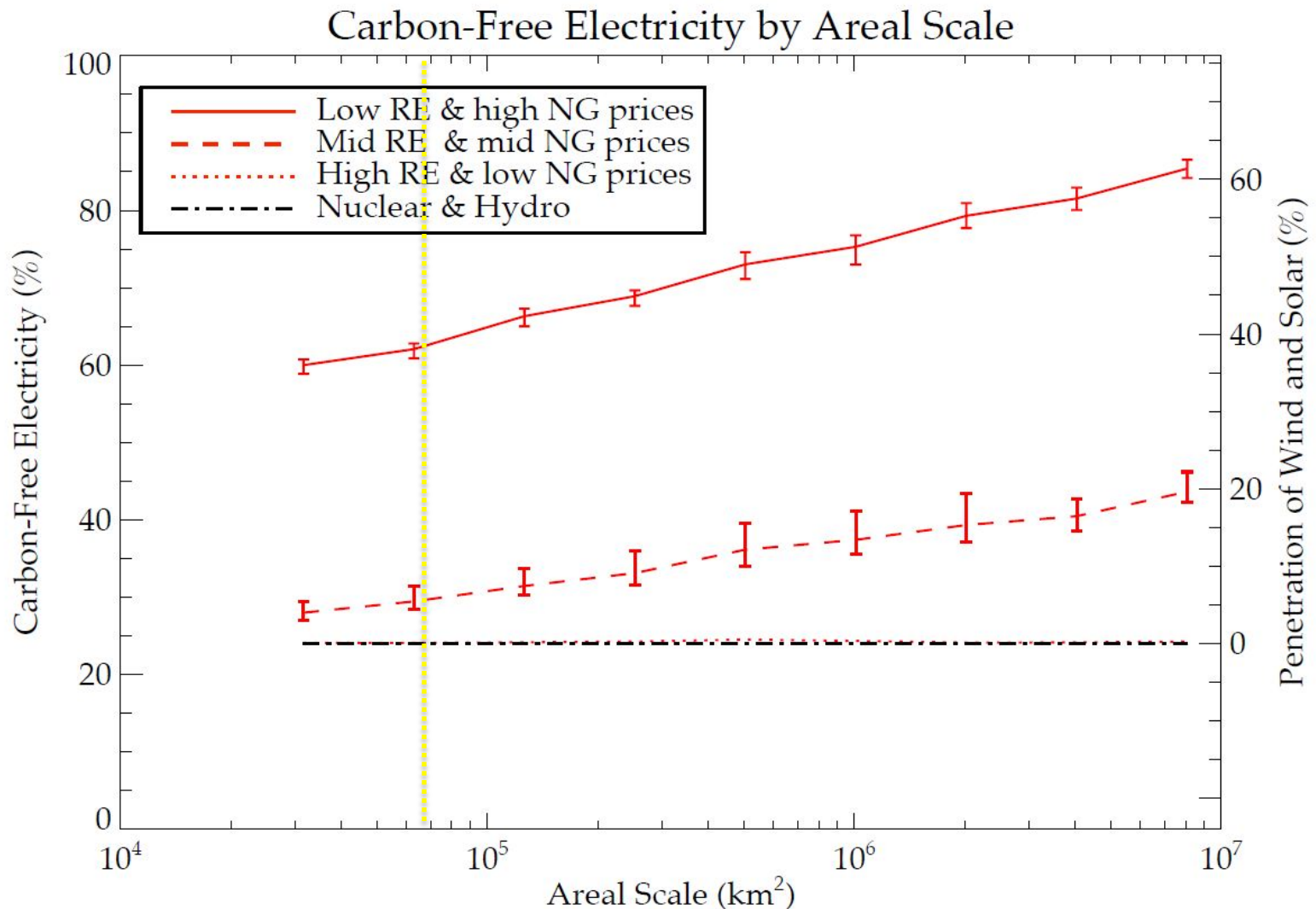


0 1 2 3 4 5



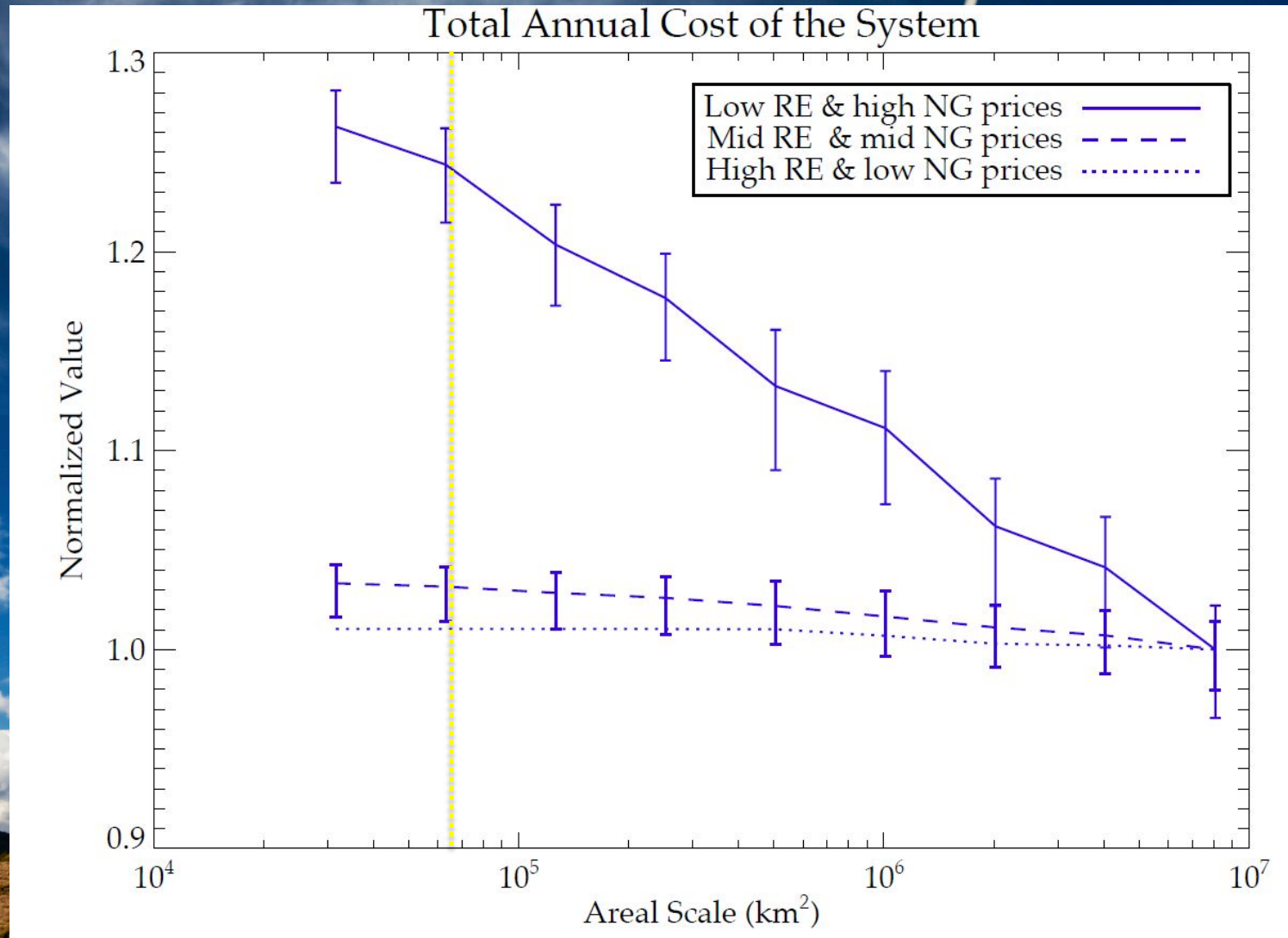
0 10 20 30 40 50 60 70

# Domain Size Sensitivity

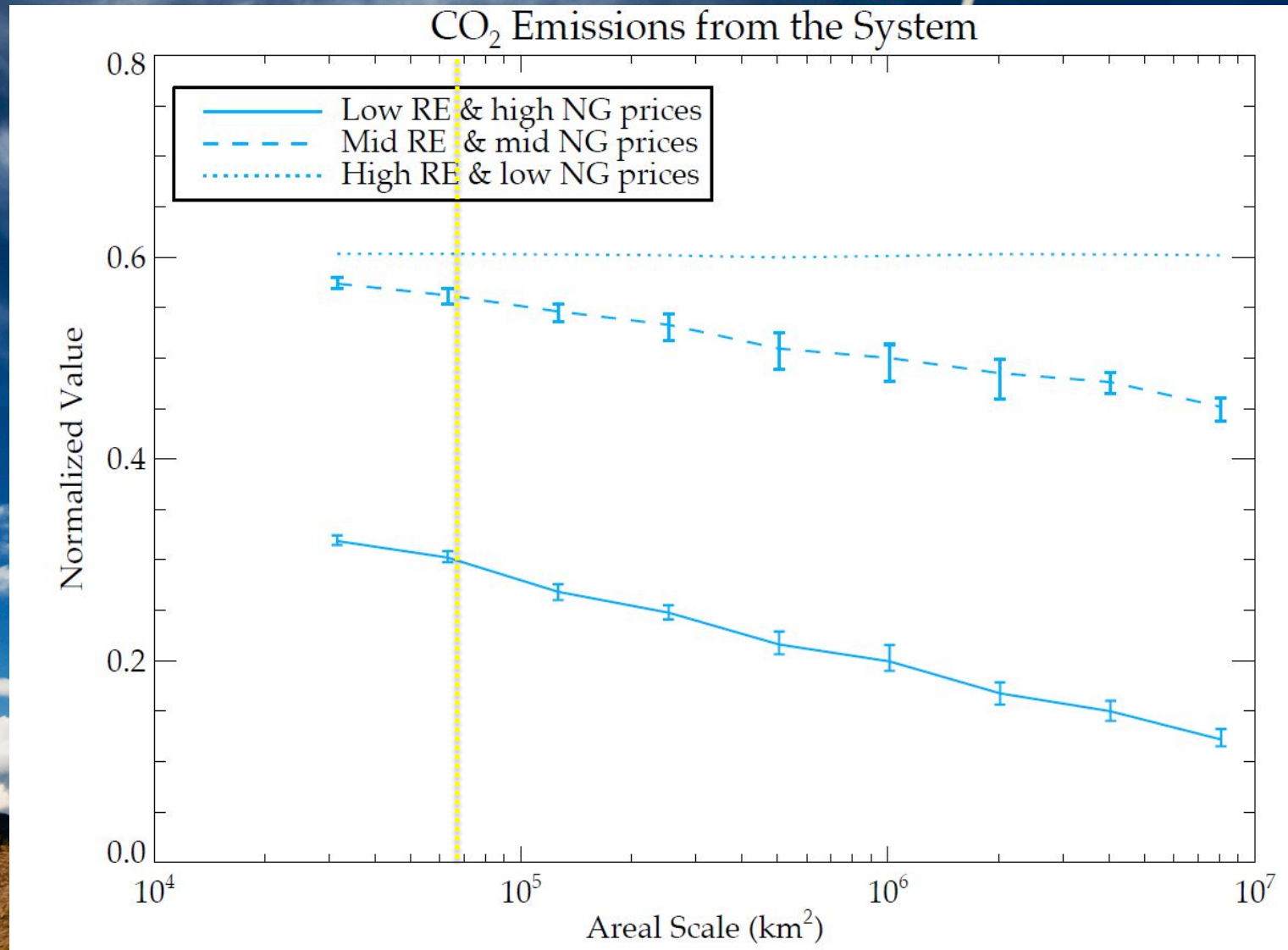




# Normalized Costs

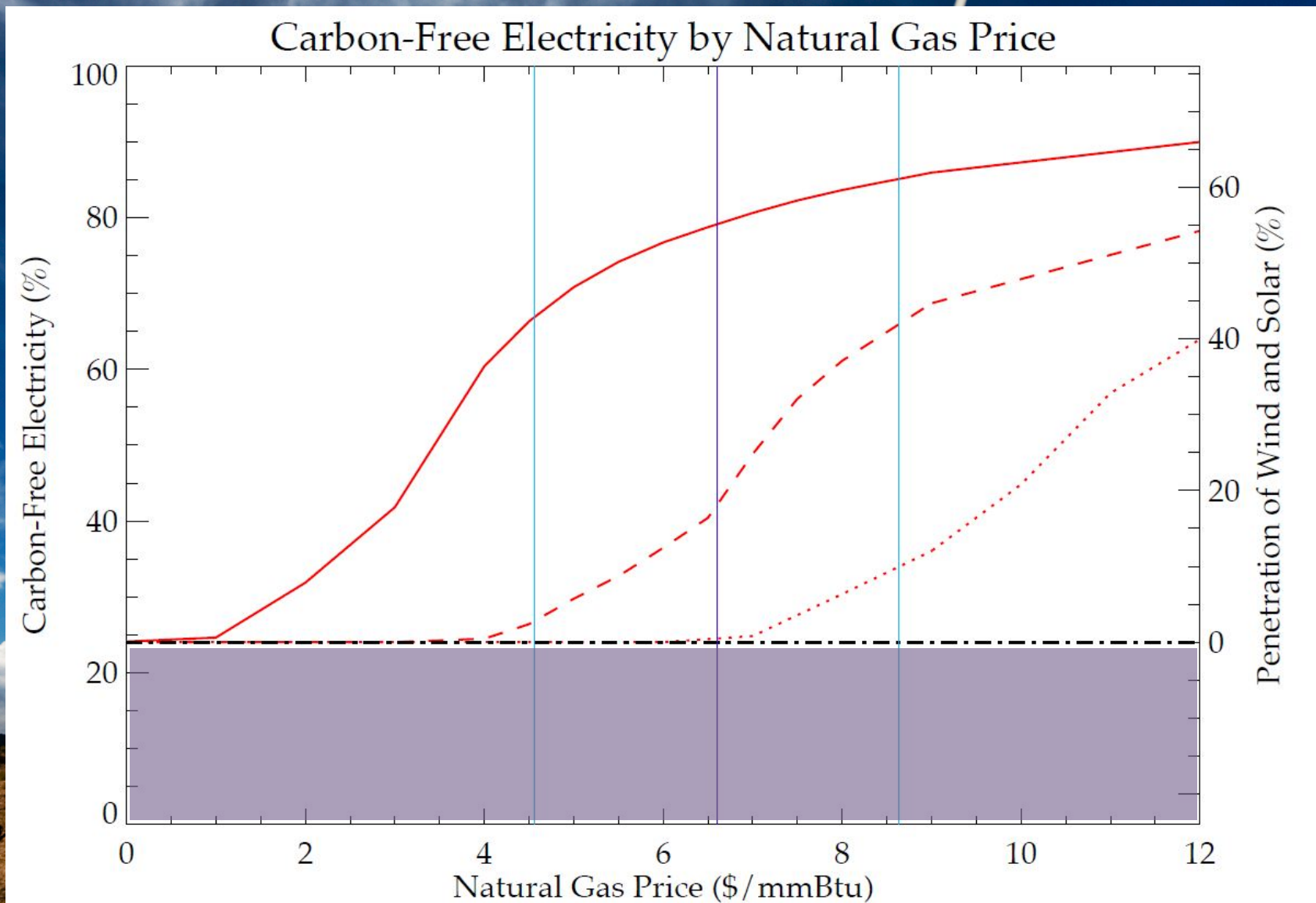


# Normalized CO<sub>2</sub> emissions

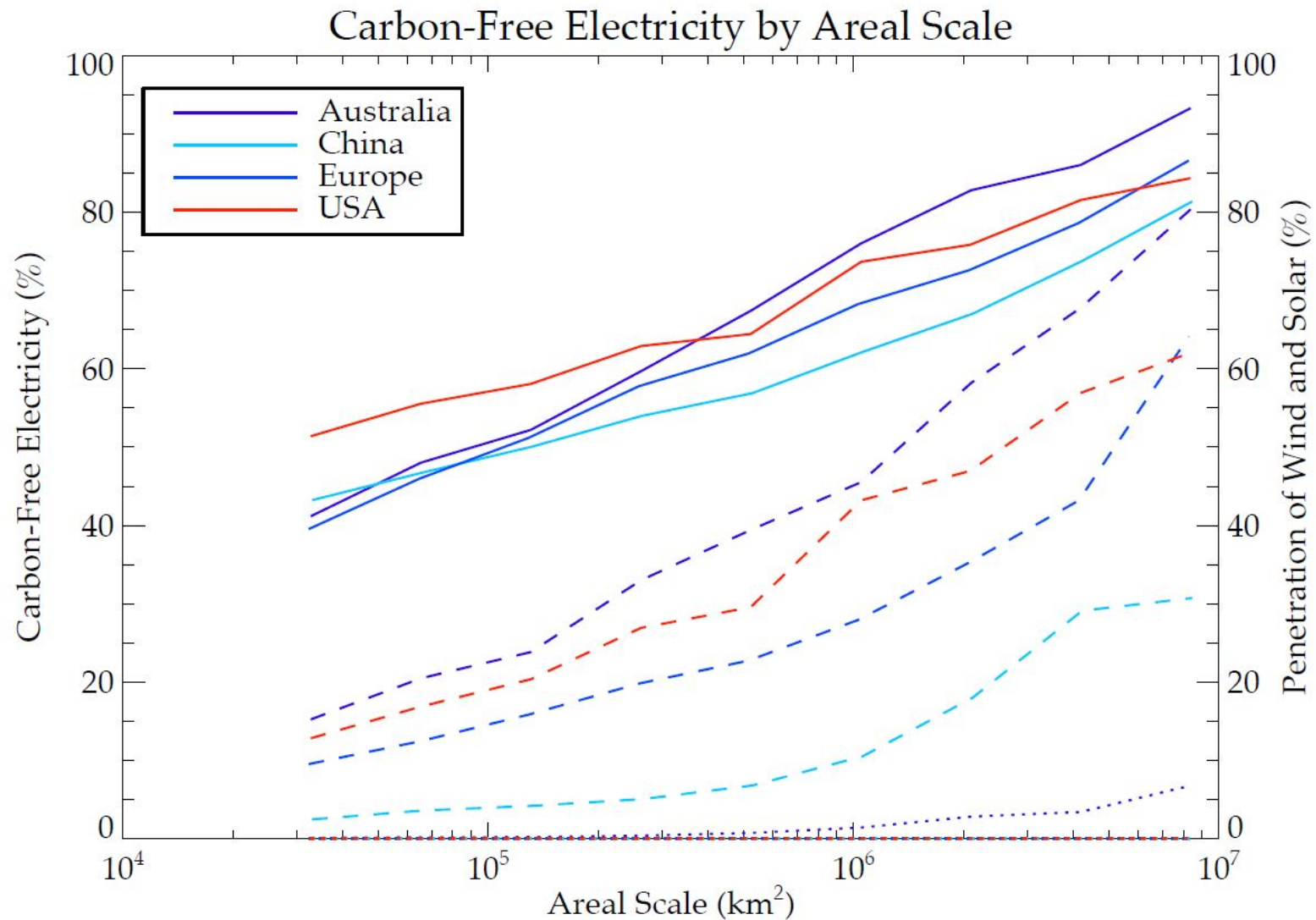




# Gas Price Sensitivity...



# Global Results...





# How does geographic scale alter the penetration of wind and solar power in the USA?

**By increasing geographic scale:**

- 1. Increase the amount of wind and solar utilized.**
- 2. Reduce the amount of CO<sub>2</sub> released into the atmosphere.**
- 3. Reduce the overall cost of the electricity produced.**
- 4. Invoke the need for a large-scale transmission system.**
- 5. This is a general result for the mid-latitude countries.**