ENERGY TECHNOLOGIES AREA

LAWRENCE BERKELEY NATIONAL LABORATORY

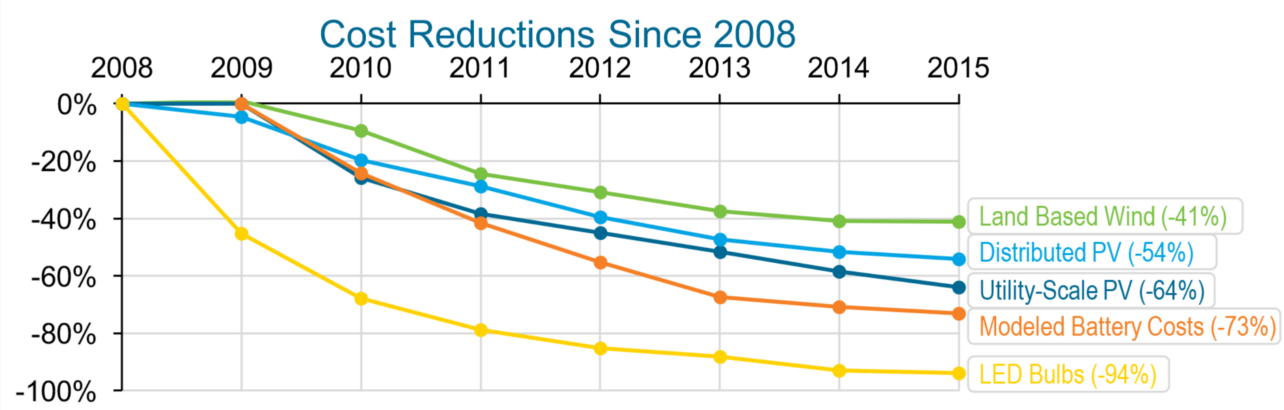
Estimating the Value of Offshore Wind Along the United States' Eastern Coast

Navy Postgraduate School
Defense Energy Seminar

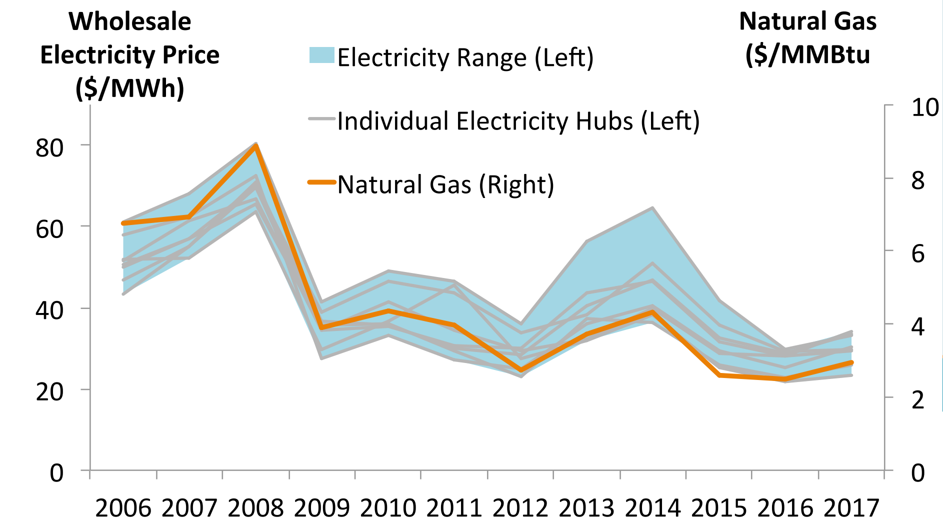
Andrew D. Mills

August 10, 2018

Prices for renewables and natural gas are at historic lows

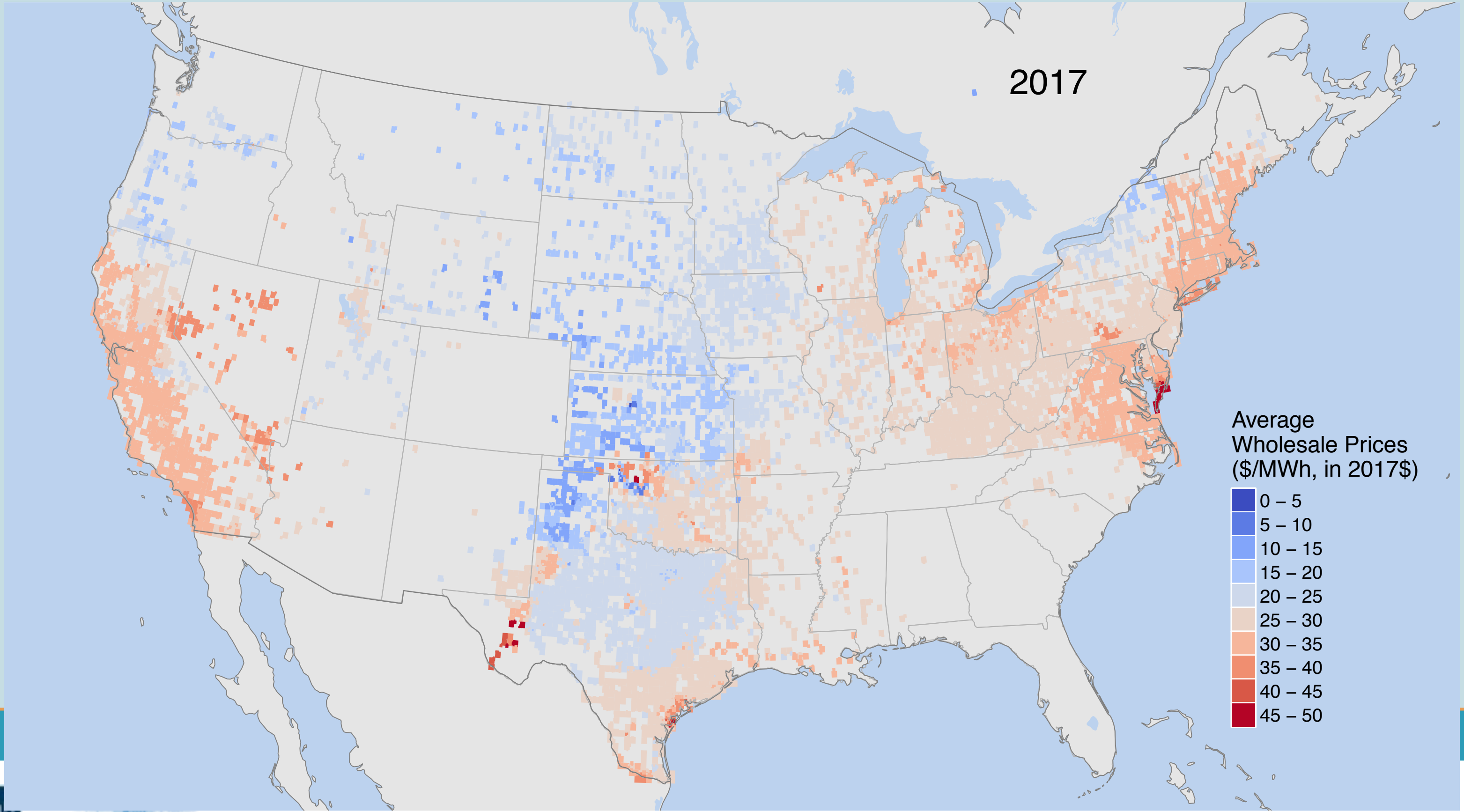


Source: Donohoo-Vallett 2016



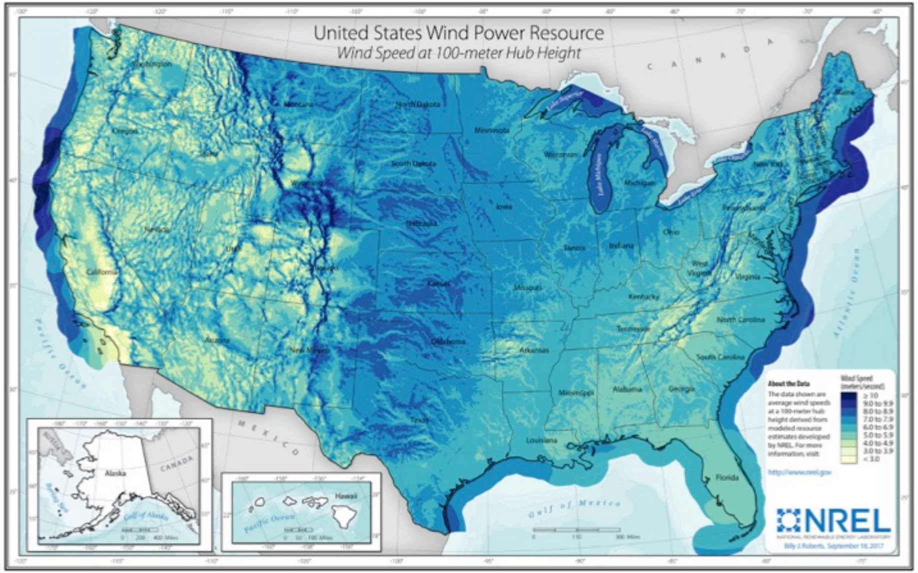
Source: Wiser et al 2017

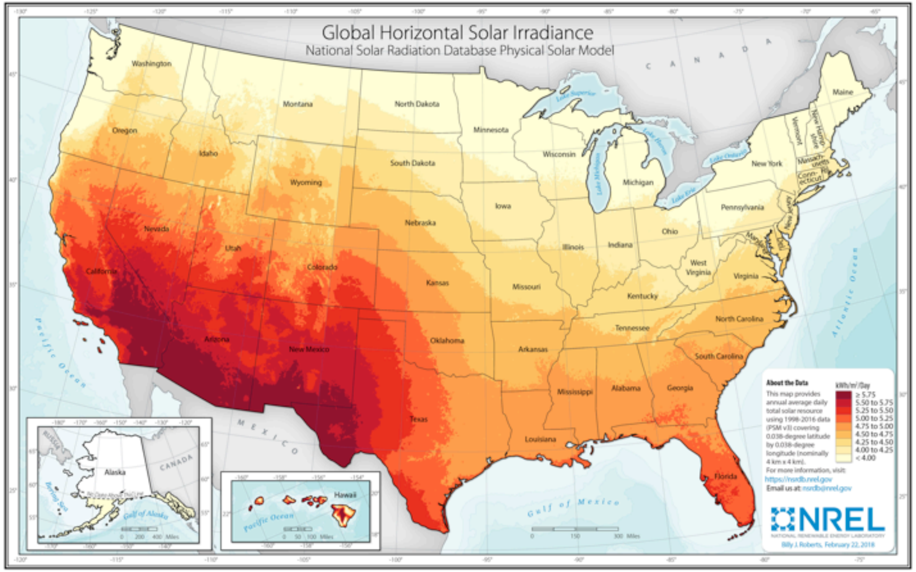
Prices for wholesale electricity are highest near the coasts



Source: LBNL analysis of ABB Velocity Suite real-time energy market prices

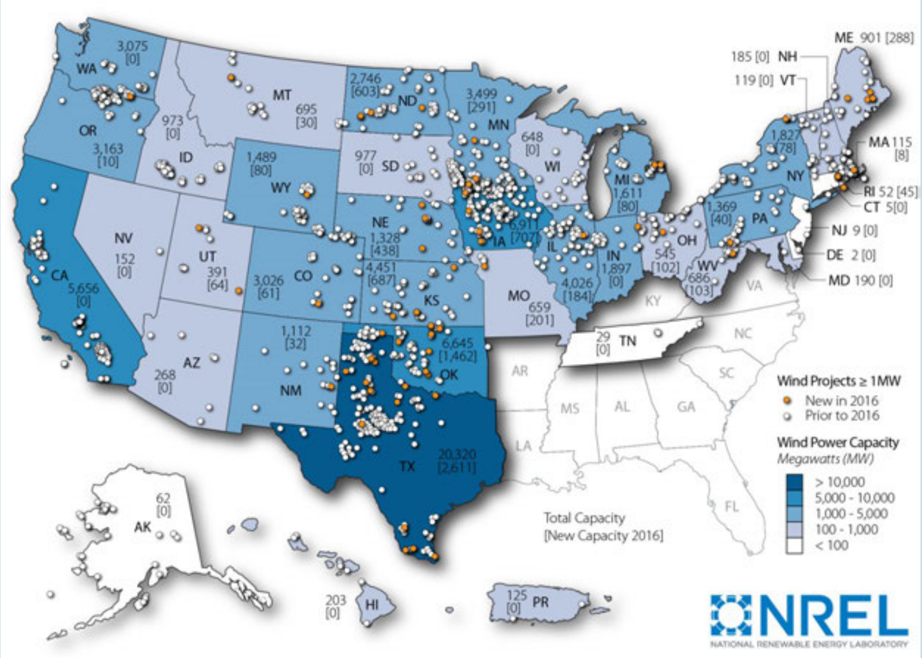
Costs of wind and solar also vary by location



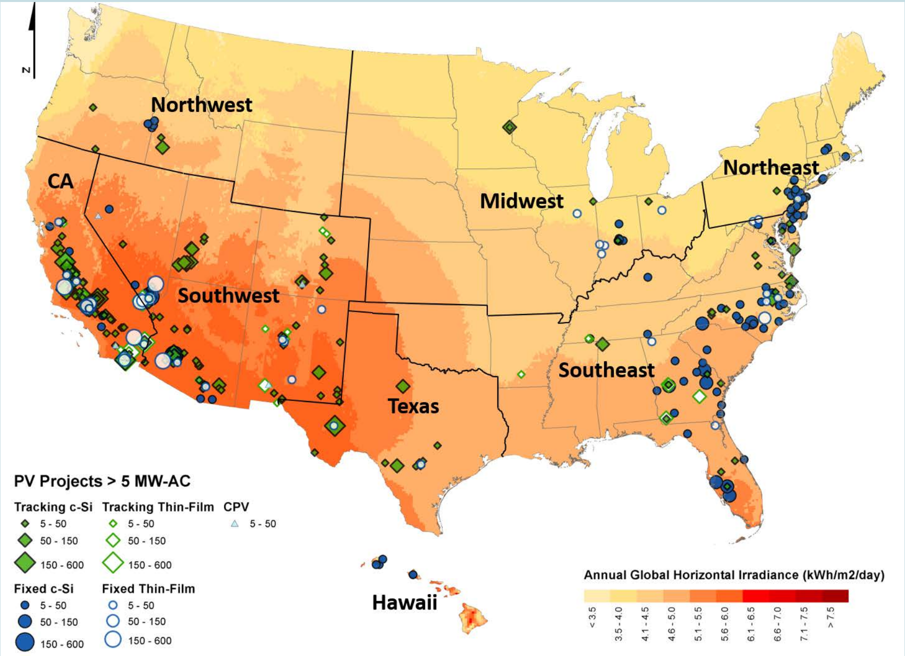


Source: NREL (www.nrel.gov/gis)

Deployment of wind and utility-scale solar through 2016



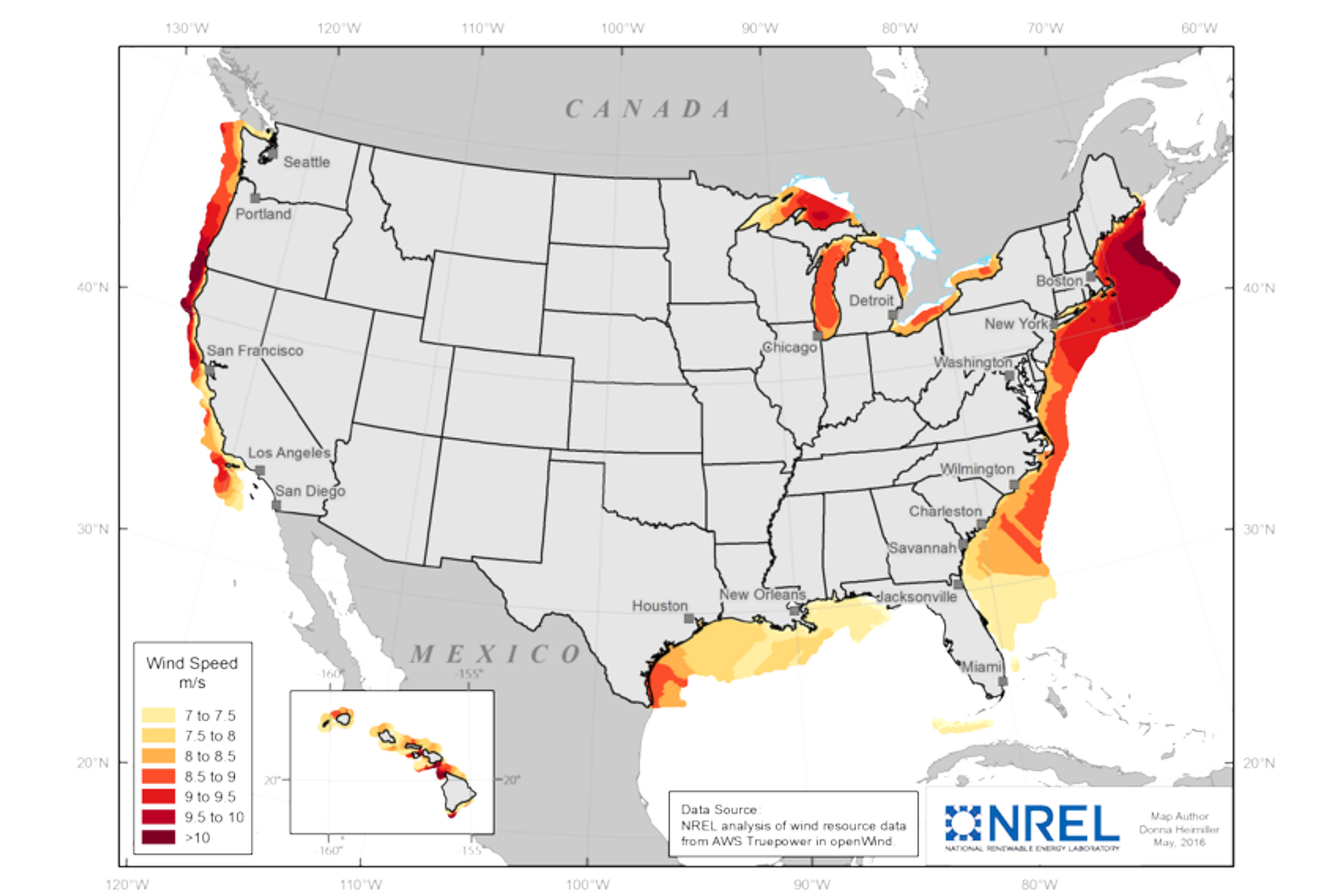
Note: Numbers within states represent cumulative installed wind capacity and, in brackets, annual additions in 2016.



Source: Wiser and Bolinger 2017

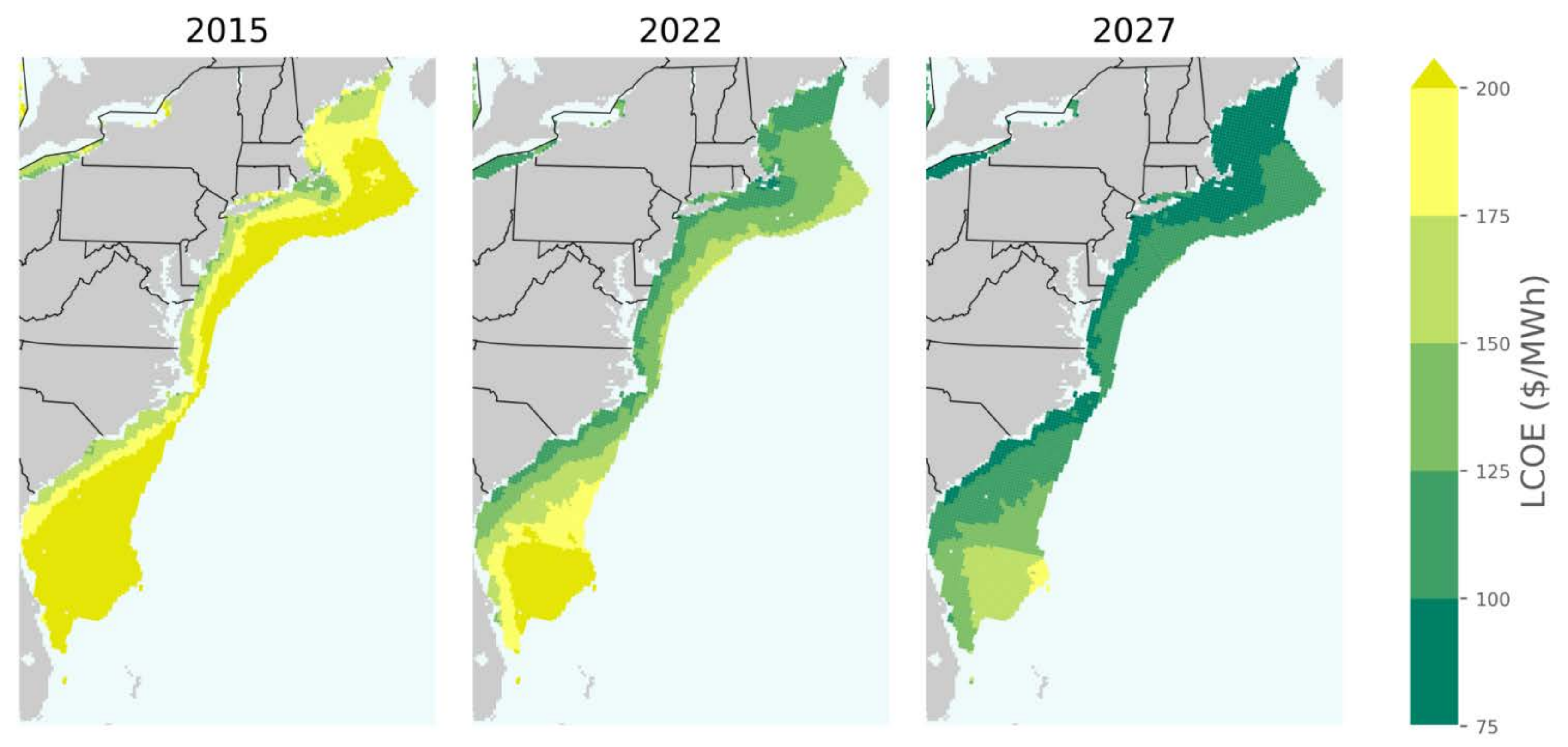
Source: Bolinger et al. 2017

Offshore wind speed are very high in some locations



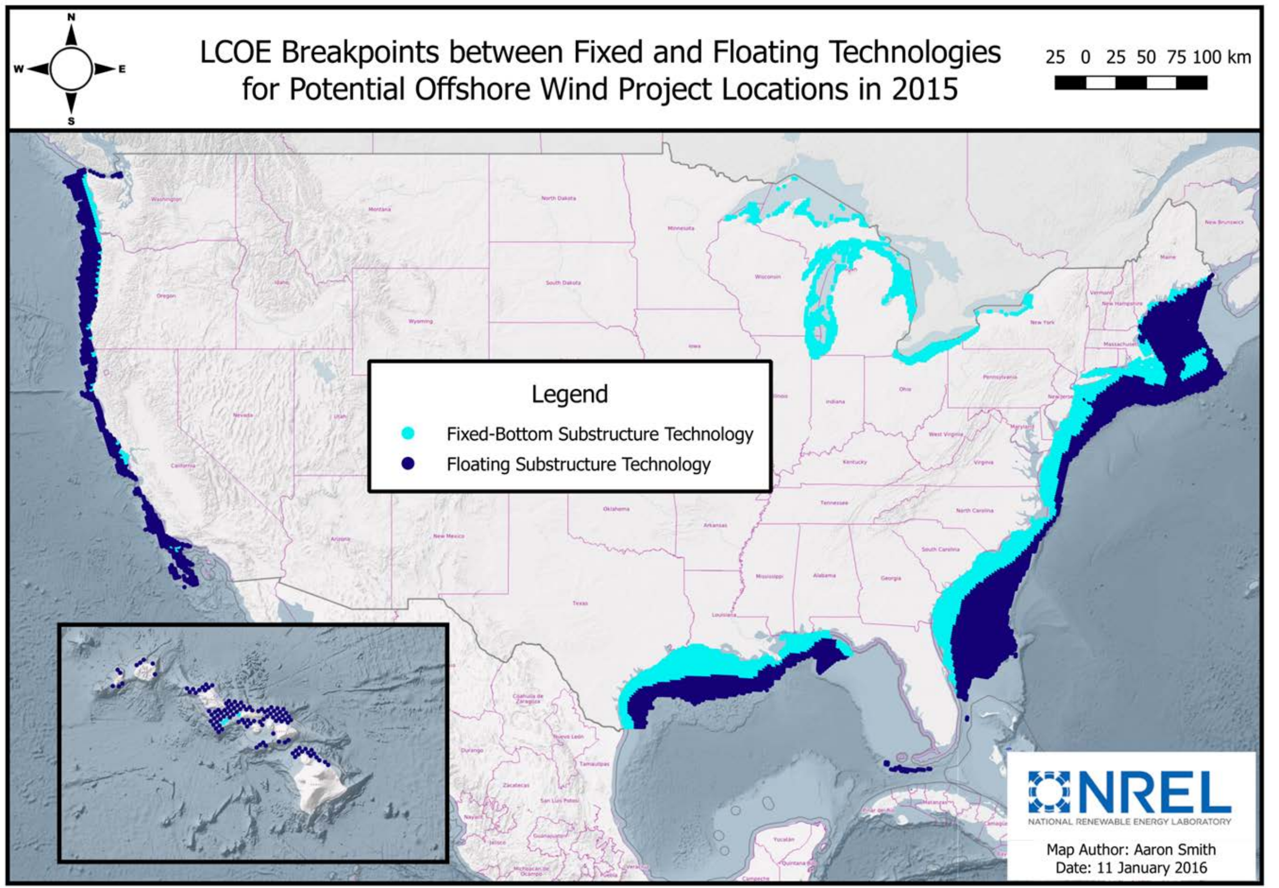
Source: Beiter et al 2016

Offshore wind costs are lowest in shallow waters with high wind speeds



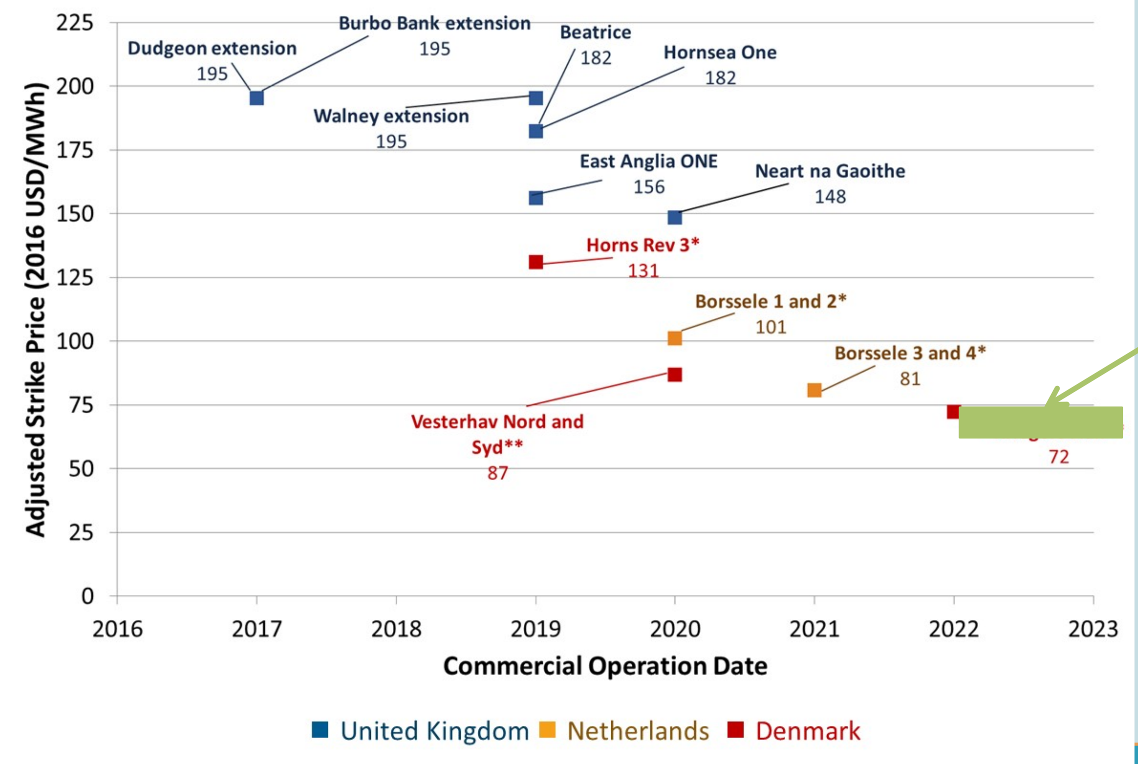
Source: Beiter et al. 2017

Fixed-bottom technologies are the least cost options for much of the East Coast



Source: Beiter et al. 2017

Decrease in prices is fueling increased interest in offshore wind in the U.S.



Vineyard Wind:
400 MW in Jan 2022, another 400 MW in Jan 2023 with $65/MWh levelized price

Source: Beiter et al 2017

Figure 1. Recent strike prices of European offshore wind winning tenders adjusted to U.S. dollars, with grid cost, development cost, and contract length adders

Notes: *Grid and development costs added; **Grid costs and contract length adjusted;

Offtaker perspective: Compare options

Buy power from spot market and meet RPS obligation with REC purchases

Buy offshore wind and deliver power to loads

Compare the direct costs of buying offshore wind to "avoided costs" from not needing to purchase power when wind is blowing

Focus on estimating and understanding this value of offshore wind

OVERVIEW

- Goal: enhance understanding of the economic value that offshore wind provides within local or regional electricity markets.
- We develop a rigorous method to estimate the marginal value provided by offshore wind, focusing on economic but also including environmental impacts.
- Diurnal and seasonal wind resource profiles vary by project location: differences can affect the value of wind power.
- What would the marginal value of offshore wind projects along the east coast of the United States have been from 2007-2016, had any such projects been operating during that time period?
- Use historical weather data combined with historical wholesale electricity market outcomes and REC prices.
- Results can inform wind developers, purchasers and energy system decision-makers.
- Also can inform U.S. Department of Energy on its offshore wind technology cost targets as well as the early-stage R&D investments necessary to reach them.

ORGANIZATION OF BRIEFING

- Key Findings
- Summary of Methods
- Primary Results
- Assessment of Future Trends
- Appendix: Methodological Details

See also a narrative summary of the key findings of this work and a journal article pre-print:

https://emp.lbl.gov/publications/estimating-value-offshore-wind-along

Note that NREL is conducting a parallel effort to assess the potential future wholesale market impacts of offshore wind in New York and New England. The NREL results will be available later in the year.

KEY FINDINGS

- The marginal total market value of offshore wind varies significantly by project location
- The market value is highest in ISO-NE in part due to higher REC prices. The energy and capacity value is higher for NYISO, particularly for the Long Island region. The value is lower in the Non-ISO region south of PJM.
- Comparing LCOE estimates with value estimates, we find that the most attractive sites from this perspective are located near southeastern Massachusetts and Rhode Island, while the least attractive are far offshore of Florida and Georgia.
- The total market value of offshore wind can be approximated (to within ±5%) by the value of a flat block of power.
- Locational variations are driven primarily by differences in average energy (and REC) prices, and not by differences in diurnal and seasonal wind generation profiles.
- Diurnal and seasonal generation profiles matter more for capacity value, which is a small component of overall value.
- The market value of offshore wind also varies significantly from year to year, driven primarily by changes to energy and REC prices. The market value of offshore wind is lowest in 2016.
- The energy and capacity value of offshore wind in the three ISO regions exceeds the value of onshore wind, by \$6/MWh – \$20/MWh in 2016.

SUMMARY OF METHODS

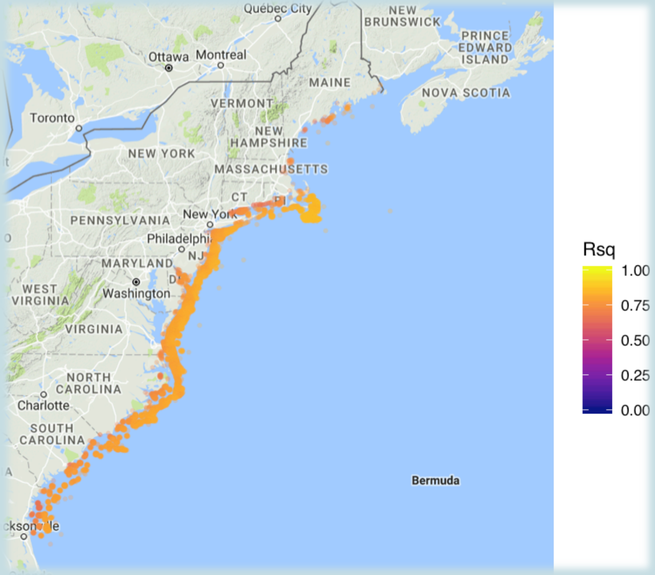
WIND SPEED

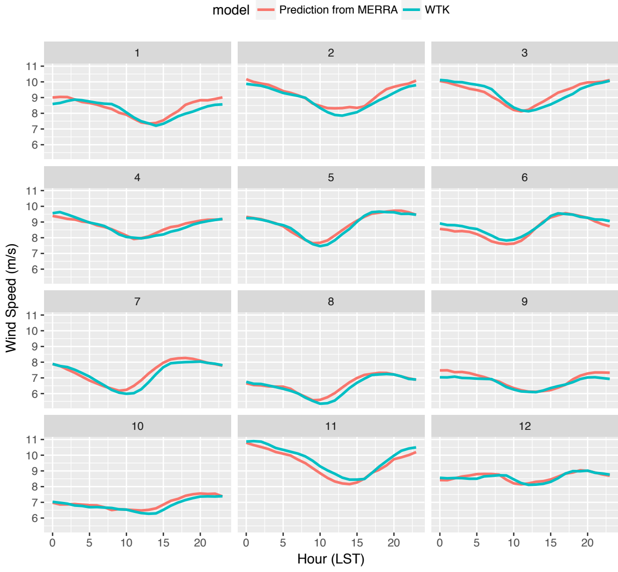
Used NREL Wind Tool Kit (WTK) to identify sites, screened for technical potential.

Used WTK data for hourly wind speeds at each site between 2007-2013.

Wind speeds for 2014-2016 estimated using reanalysis (MERRA) data available at coarse geographic resolution.

Downscaled coarse MERRA data to the WTK sites





- Cross validation showed that the approach can effectively recreate the WTK diurnal and seasonal cycles.
- Average R^2 value: 0.8 for 2007 – 2013 cross validation (~6,700 sites)

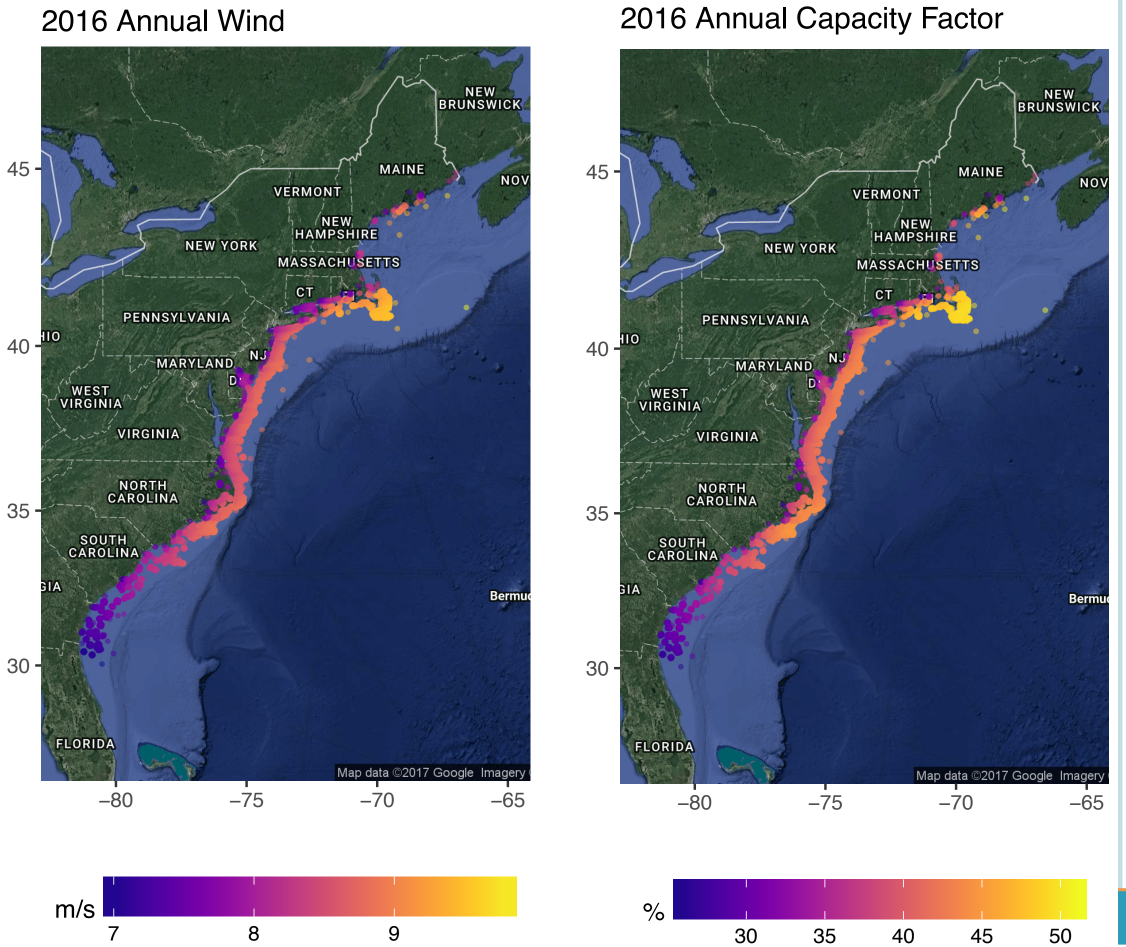
WIND POWER

Converted wind speed to hourly gross wind power output for 6 MW offshore turbine power curve.

Net hourly wind power output accounts for four sources of losses:

- *Wake losses*
- *Electrical losses*
- *Availability*
- *Other losses*

Other assumptions: For simplicity, air density was treated as constant across time.

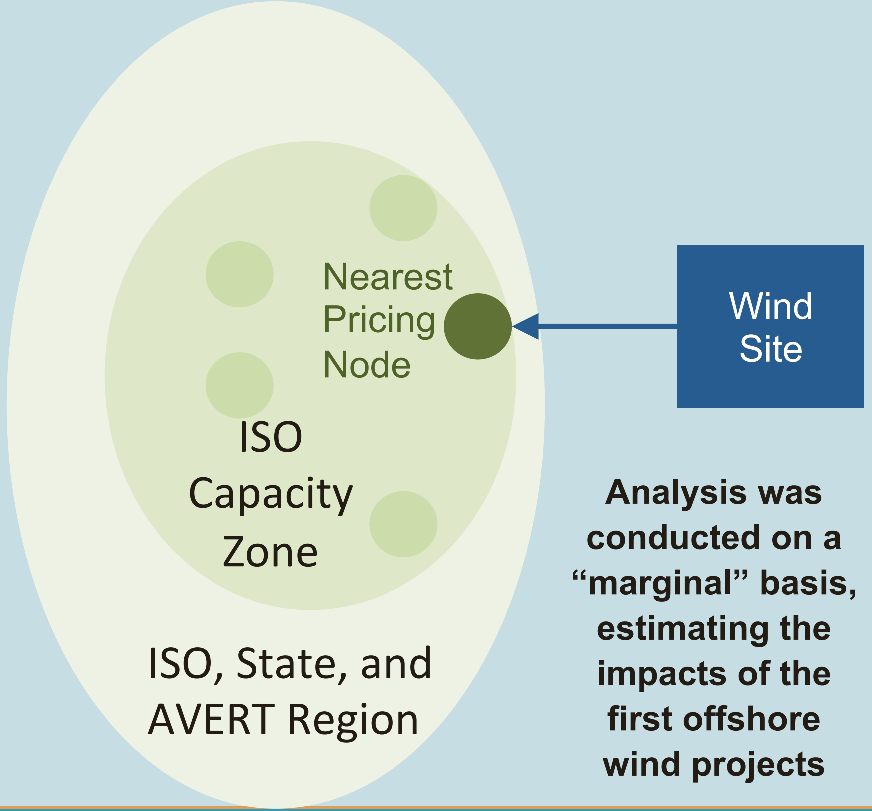


2016 annual average hourly wind speed (left) and energy generation (right) for all sites (~6,700)

VALUE CALCULATIONS

Marginal impacts were estimated using recent historical prices and emissions rates for 2007-2016.*

- *Energy value:* hourly nodal real-time energy prices (referred to as locational marginal prices, or, LMPs)
- *Capacity value:* ISO capacity zone prices and capacity credits estimated using each ISO's practices
- *REC value:* monthly Tier 1/Class 1 REC prices for each state and monthly wind power
- *Avoided emissions:* EPA's AVERT model for each year
- *Wholesale price effect:* reduction in wholesale energy prices from historical relationship of price and demand
- *Natural gas price effect:* reduction in gas from AVERT, with price elasticity from EIA



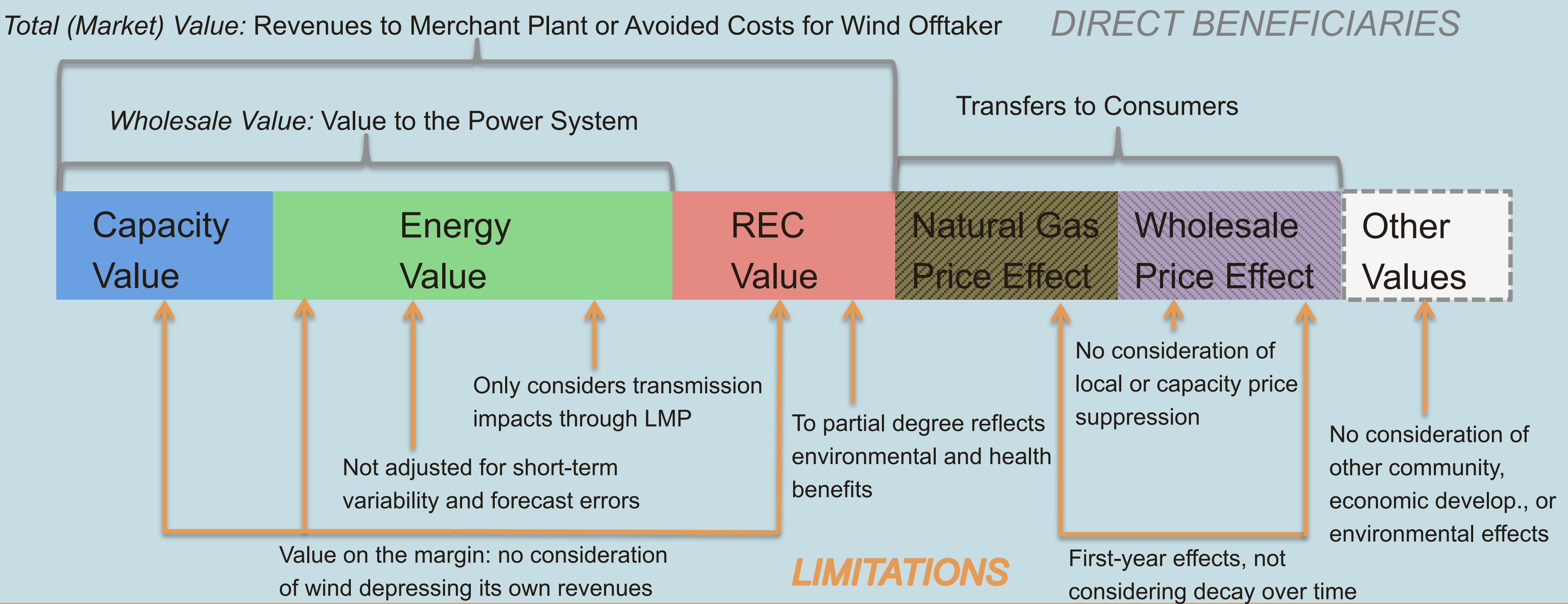
Analysis was conducted on a "marginal" basis, estimating the impacts of the first offshore wind projects

*Additional information on the methods used for each category are detailed in the appendix

CAPACITY MARKET RULES VARY BY ISO

	ISO-NE	NYISO	PJM
Seasons	Summer and Winter	Summer and Winter	Summer
Summer Peak Period	June-Sept 1-6pm	June-Aug 2-6pm	June-Aug 2-6pm
Winter Peak Period	Oct-May 5-7pm	Dec-Feb 4-8pm	N/A
Basis of Measurement	Median during peak	Average during peak	Average during peak
Average over which years?	Rolling average over previous 5 years	Previous year	Rolling average over previous 3 years

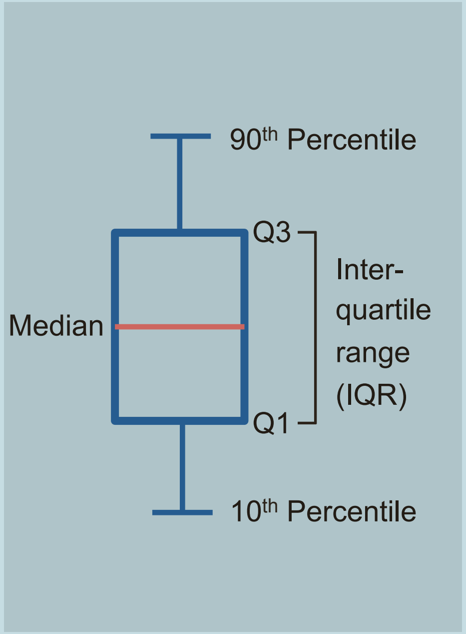
SUMMARY OF VALUE STREAMS CONSIDERED OR EXCLUDED FROM ANALYSIS



PRIMARY RESULTS

- Energy, capacity, and REC value, by location and over time
- Normalized value relative to flat baseload block
- Offshore capacity credit: summer and winter
- Value comparisons with onshore (land-based) wind
- Avoided air pollution emissions
- Wholesale price "merit-order" effect
- Natural gas price suppression effect

Guide to reading the box and whisker plots



ENERGY, CAPACITY, AND REC VALUE

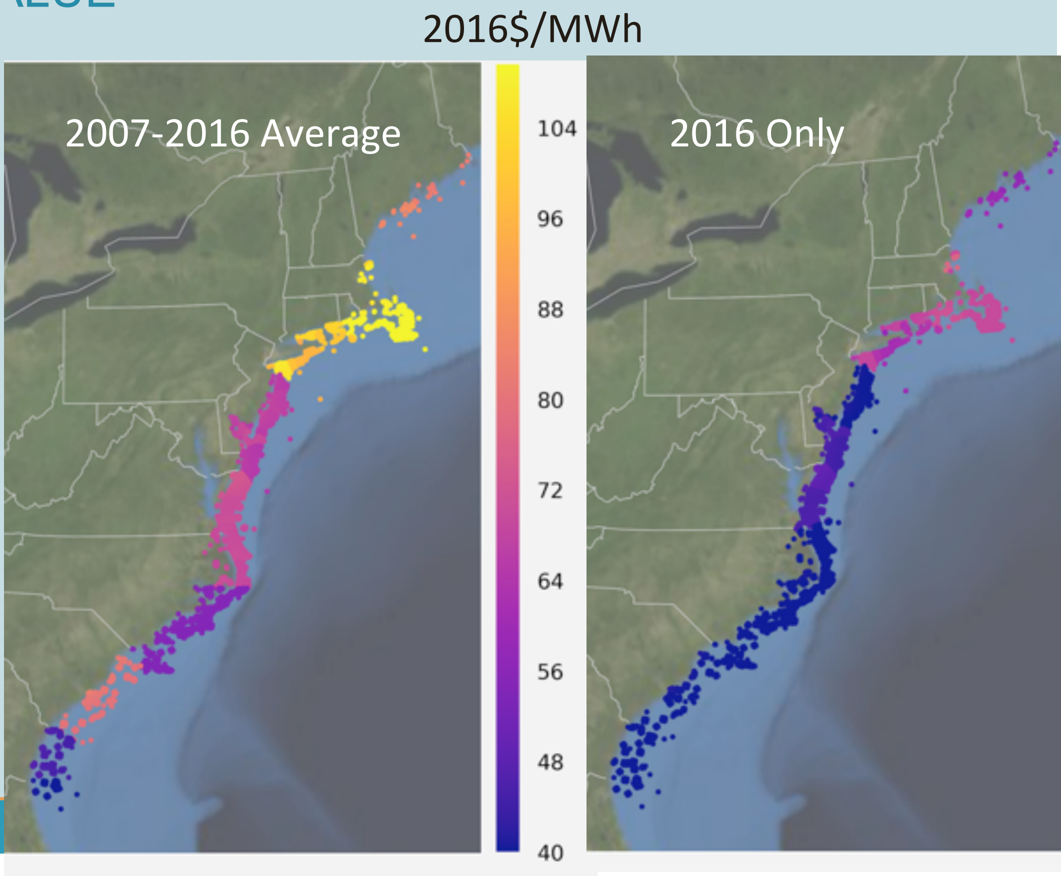
Total average energy, capacity, and REC value over 2007-2016 is highest near NY, CT, RI, and MA.

The value is lowest in 2016, though the geographic variation in value is similar in 2016 to the variation over 2007-2016.

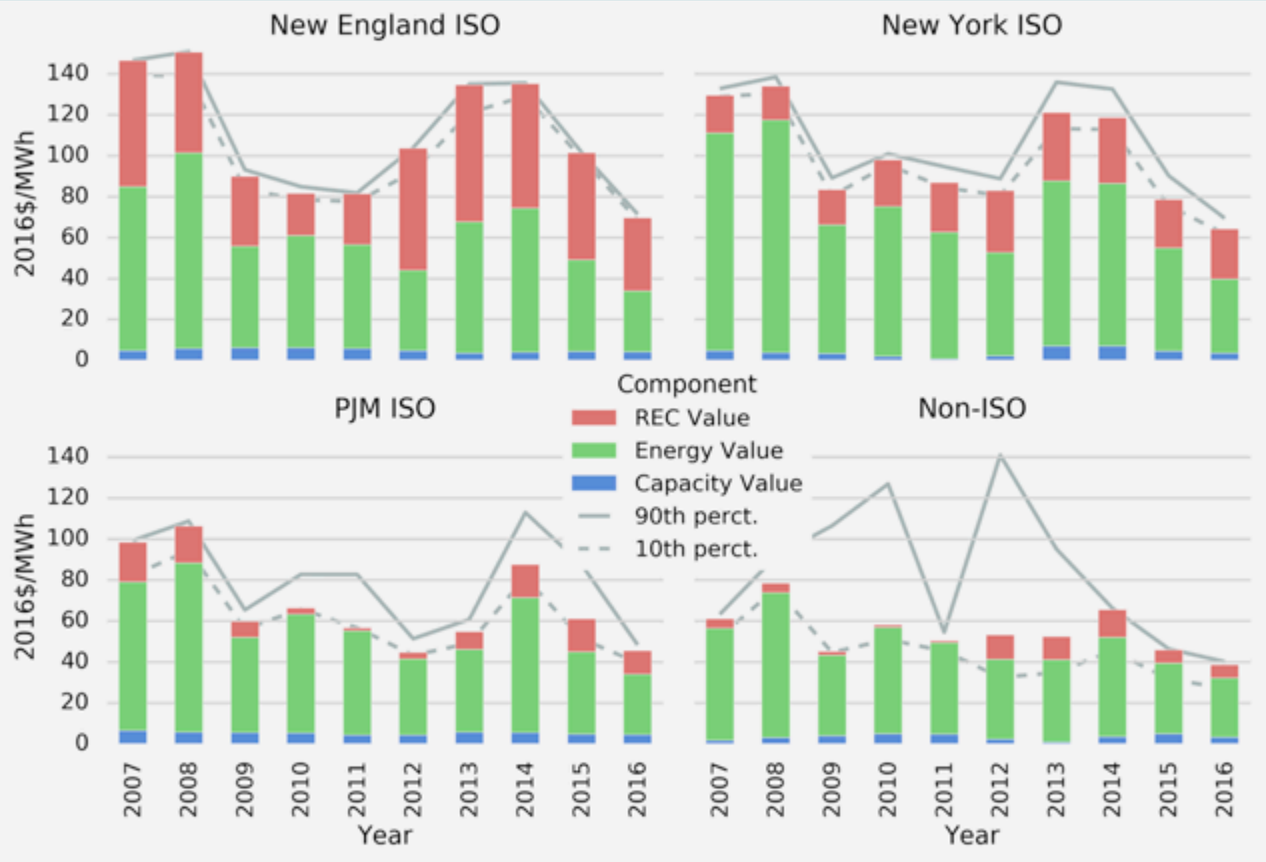
Across 2007-2016, the median value for sites is around \$110/MWh in ISO-NE, \$100/MWh in NYISO, \$70/MWh in PJM, and \$55/MWh in the Non-ISO region south of PJM.

Variation in total value across sites is primarily driven by variation in electricity and REC prices rather than in wind power profiles.

Lower value in 2016 is driven primarily by the lower LMPs and REC prices.



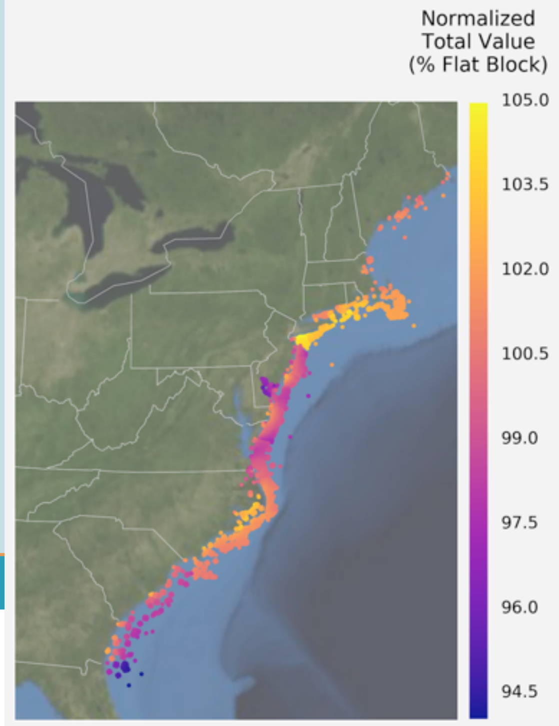
VALUE COMPONENTS

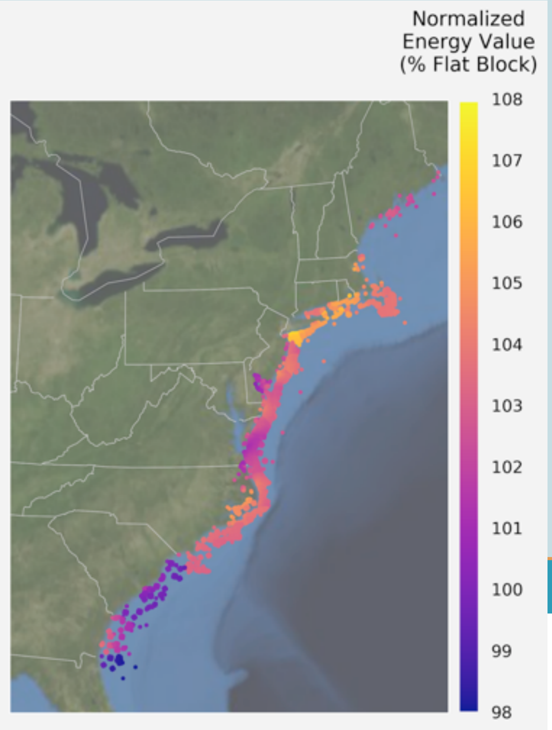


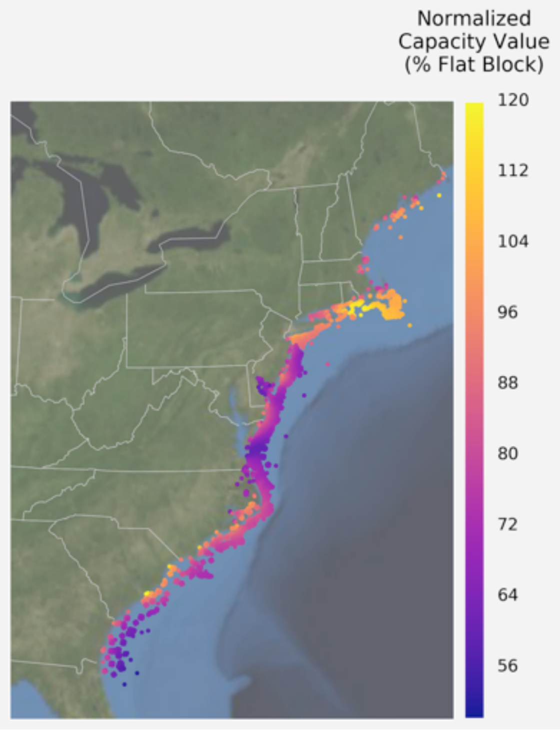
NORMALIZED VALUE HIGHLIGHTS EFFECT OF WIND VARIABILTY

For most sites, the value of offshore wind with its actual historical profile is very close to that of a flat block (within 98-105%).

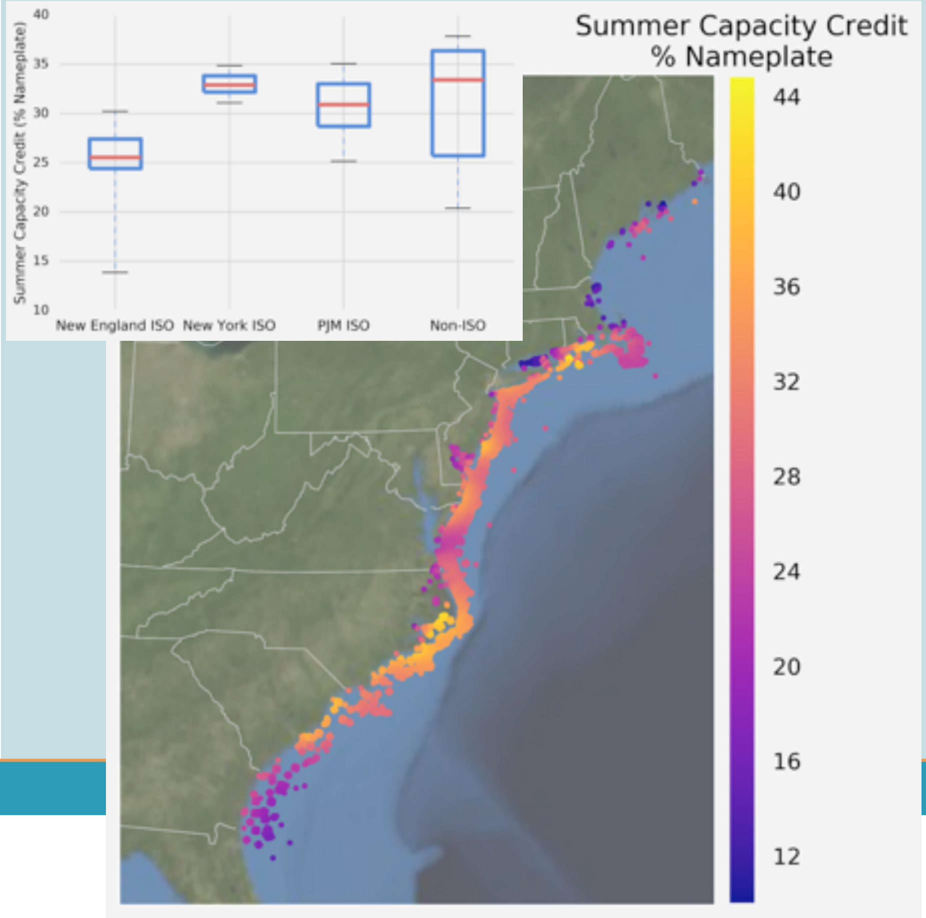
Most sites in ISO-NE have a capacity value that exceeds the capacity value of a flat block of power. This is in part due to the high capacity credit of offshore wind in the winter months (shown on next slide). The capacity value in PJM and the non-ISO region is typically less than a flat block of power.

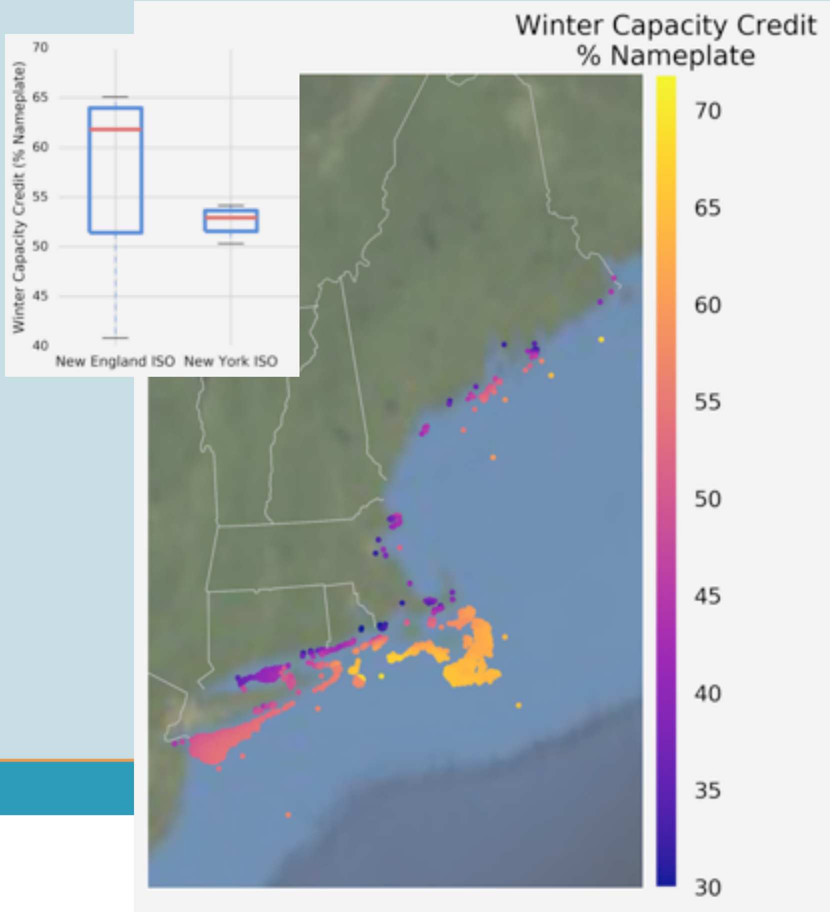






SUMMER AND WINTER CAPACITY CREDIT





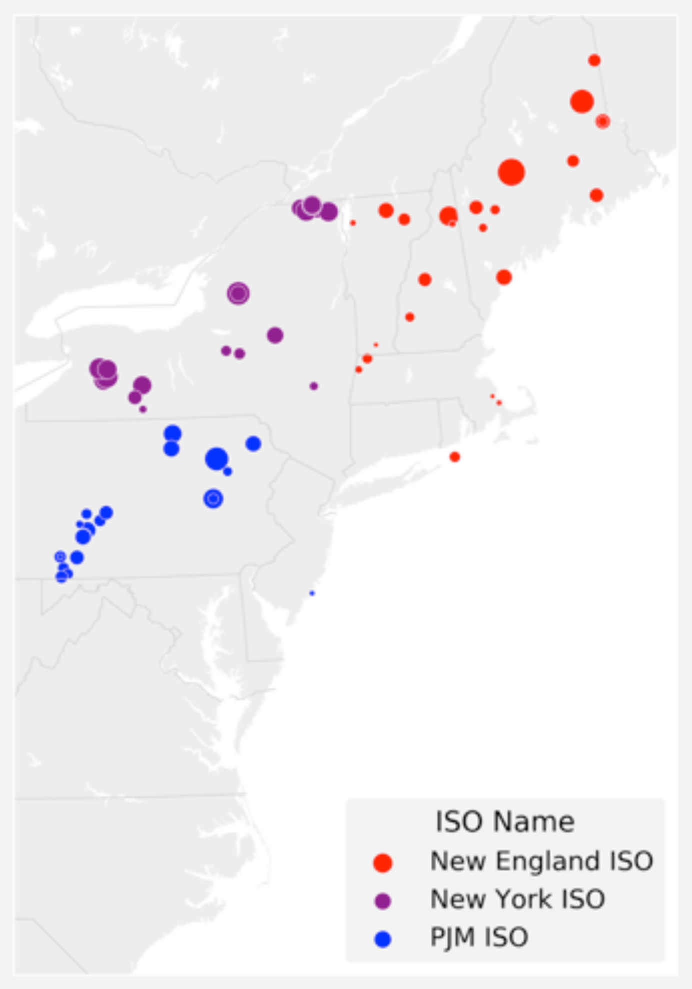
ONSHORE WIND ALTERNATIVES

Compare the energy and capacity value of offshore wind to onshore wind.

The onshore wind value is based on the aggregate hourly wind profile in ISO-NE, NYISO, and the Mid-Atlantic region of PJM.

Energy value based on the capacity-weighted average hourly LMP price and the aggregate wind profile, for each ISO.

Capacity value based on the capacity-weighted average zonal capacity price and the capacity credit of the average wind profile.



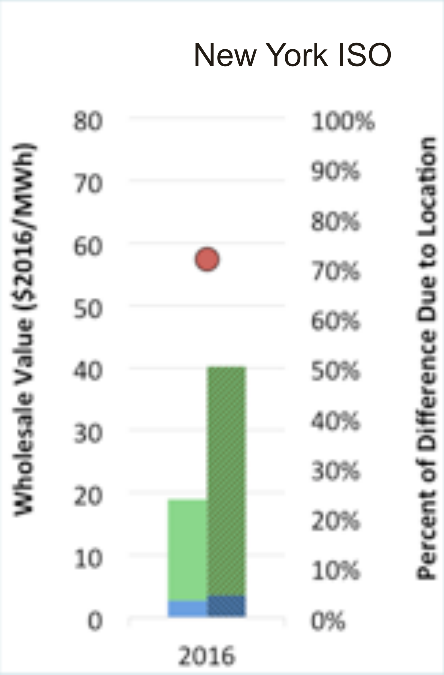
ONSHORE WIND ALTERNATIVES

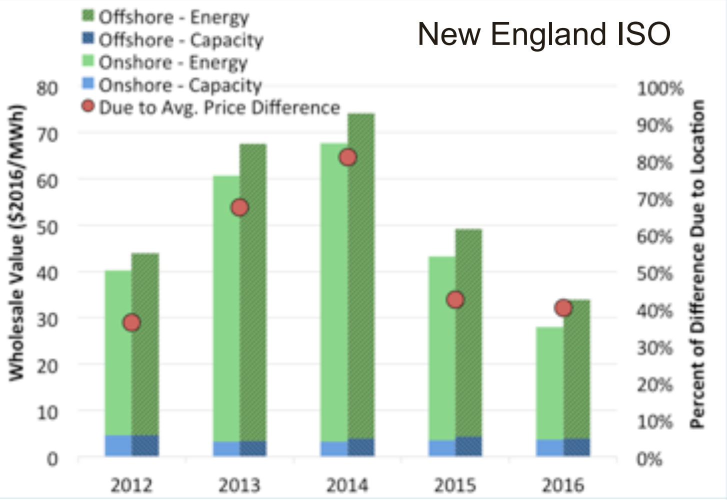
Value of offshore wind exceeds the value of onshore wind

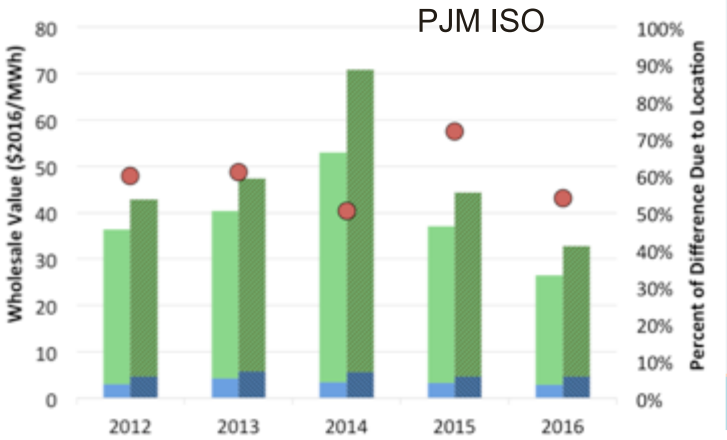
Difference in wholesale value due to differences in:

- Location
- Hourly output profiles

Red dots highlight difference due to location







ONSHORE WIND ALTERNATIVES

ISO Name	Capacity Credit (% Nameplate)			
	Summer		Winter	
	Onshore	Offshore	Onshore	Offshore
New England ISO	15%	24%	30%	63%
New York ISO	19%	39%	37%	61%
PJM ISO	14%	31%	n/a	n/a

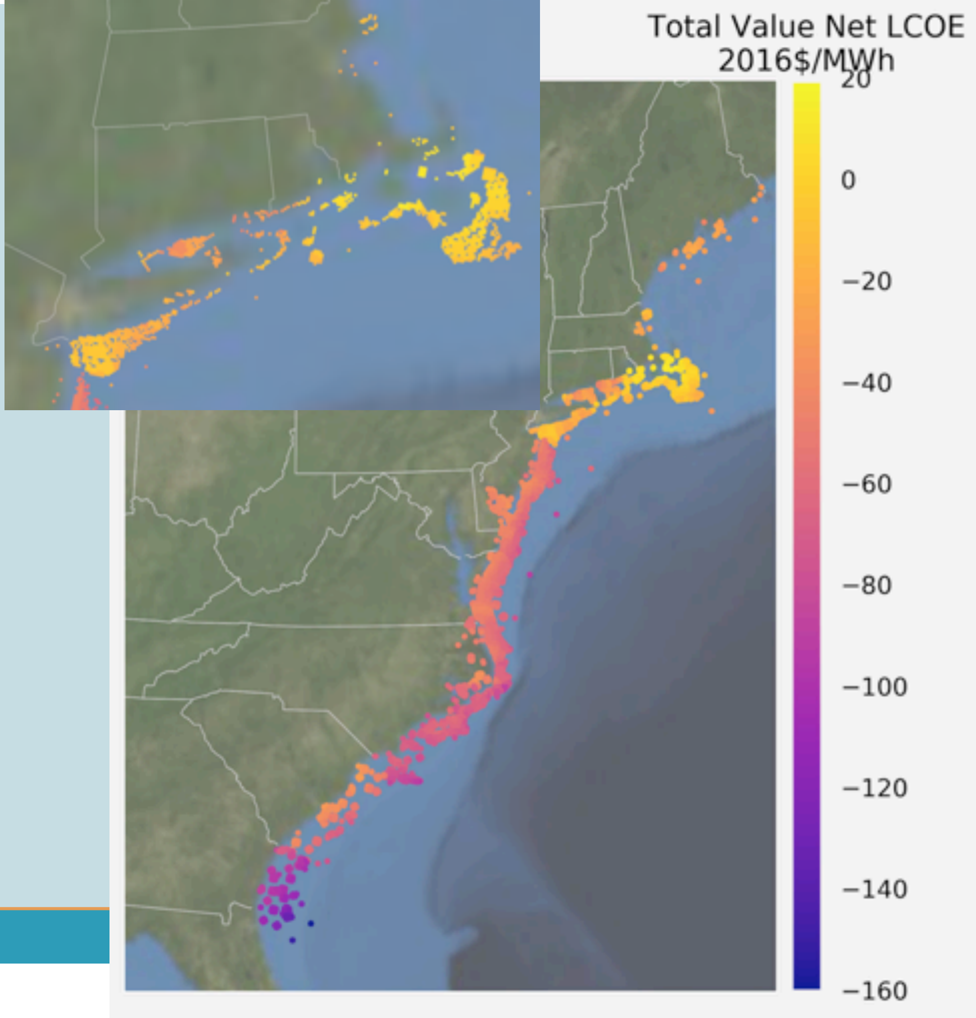
HIGHEST VALUE NET OF COSTS

The most attractive offshore wind sites will have the highest value net of the cost of offshore wind.

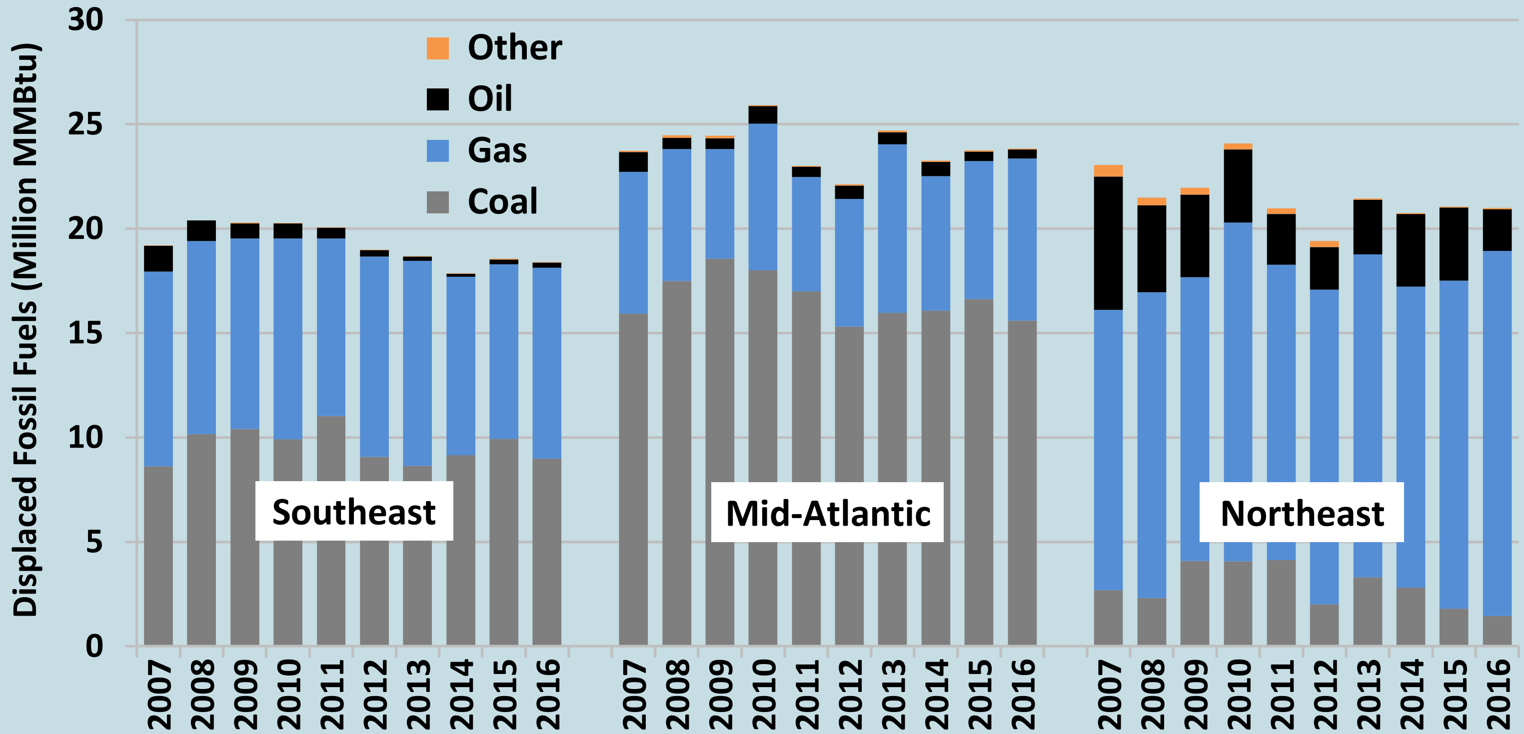
Relative ranking of sites based on difference between total market value and levelized cost of energy.

Most attractive sites are near southeastern Massachusetts and Rhode Island.

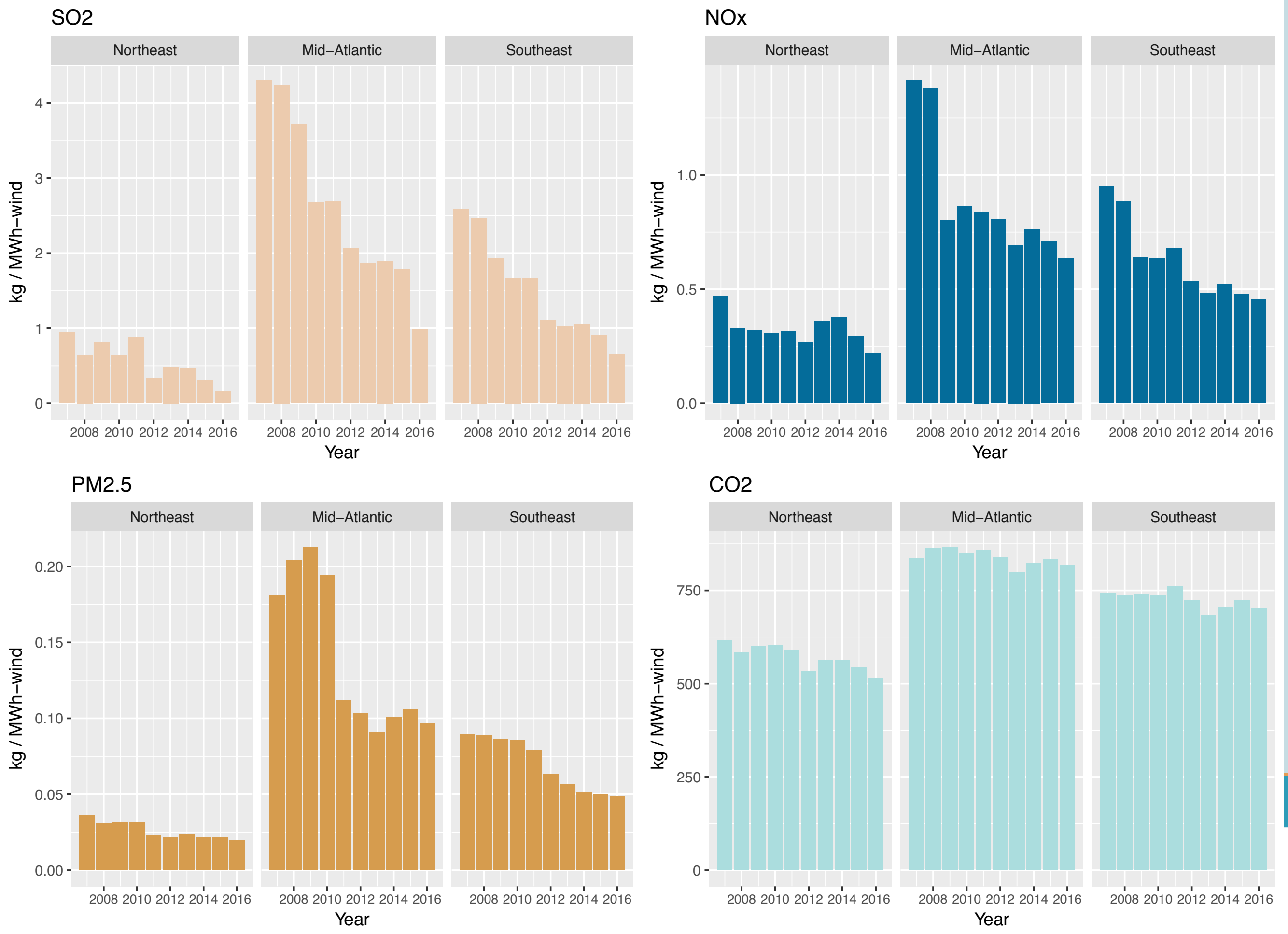
The least attractive sites are far offshore of Florida and Georgia.



DISPLACED FOSSIL GENERATION



AVOIDED AIR EMISSIONS

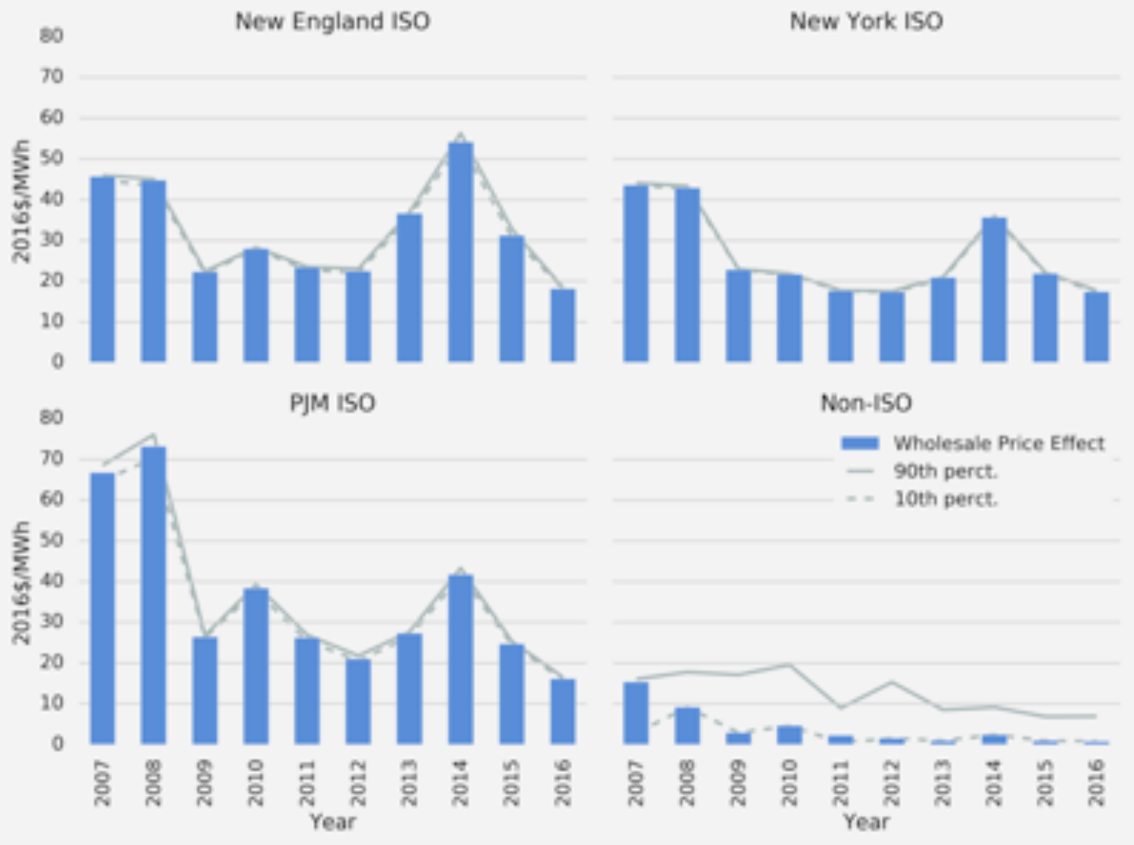


WHOLESALE ELECTRICITY PRICE EFFECT

Depends on the slope of the supply curve and the amount of load that purchases wholesale power at spot market prices.

Year to year variation as changes in natural gas prices change the slope of the supply curve.

Represents a transfer of wealth from producers to consumers.



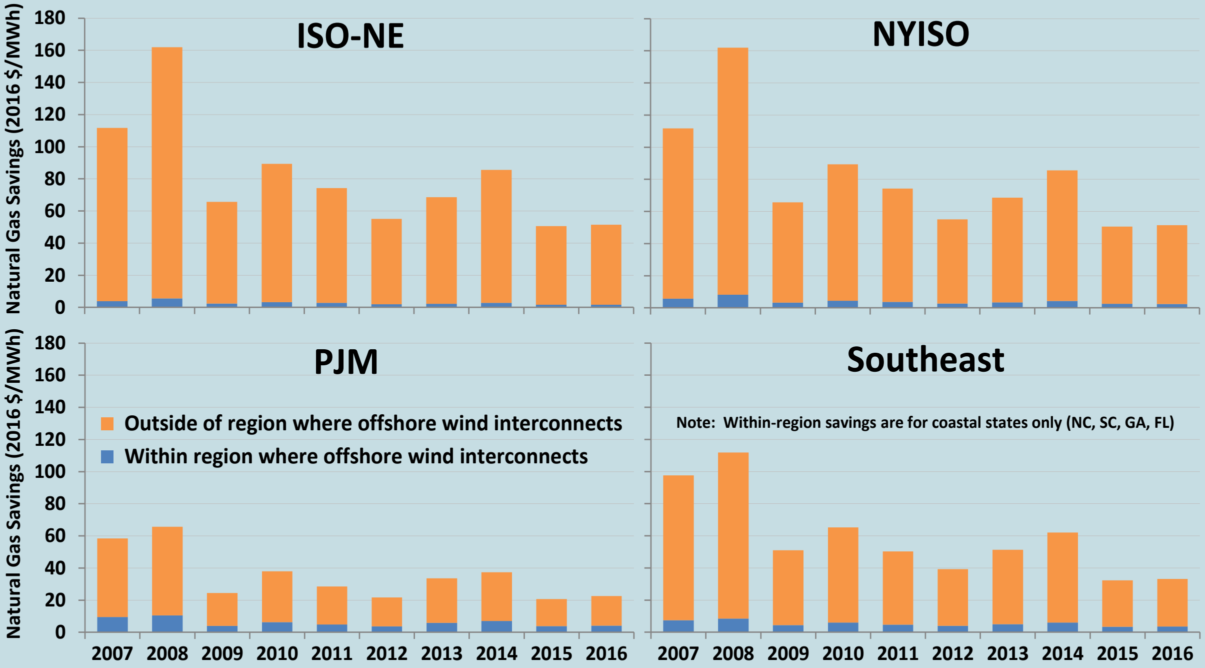
NATURAL GAS PRICE EFFECT

Depends on how much gas-fired generation wind displaces, inverse price elasticity of natural gas supply, and the level of natural gas prices.

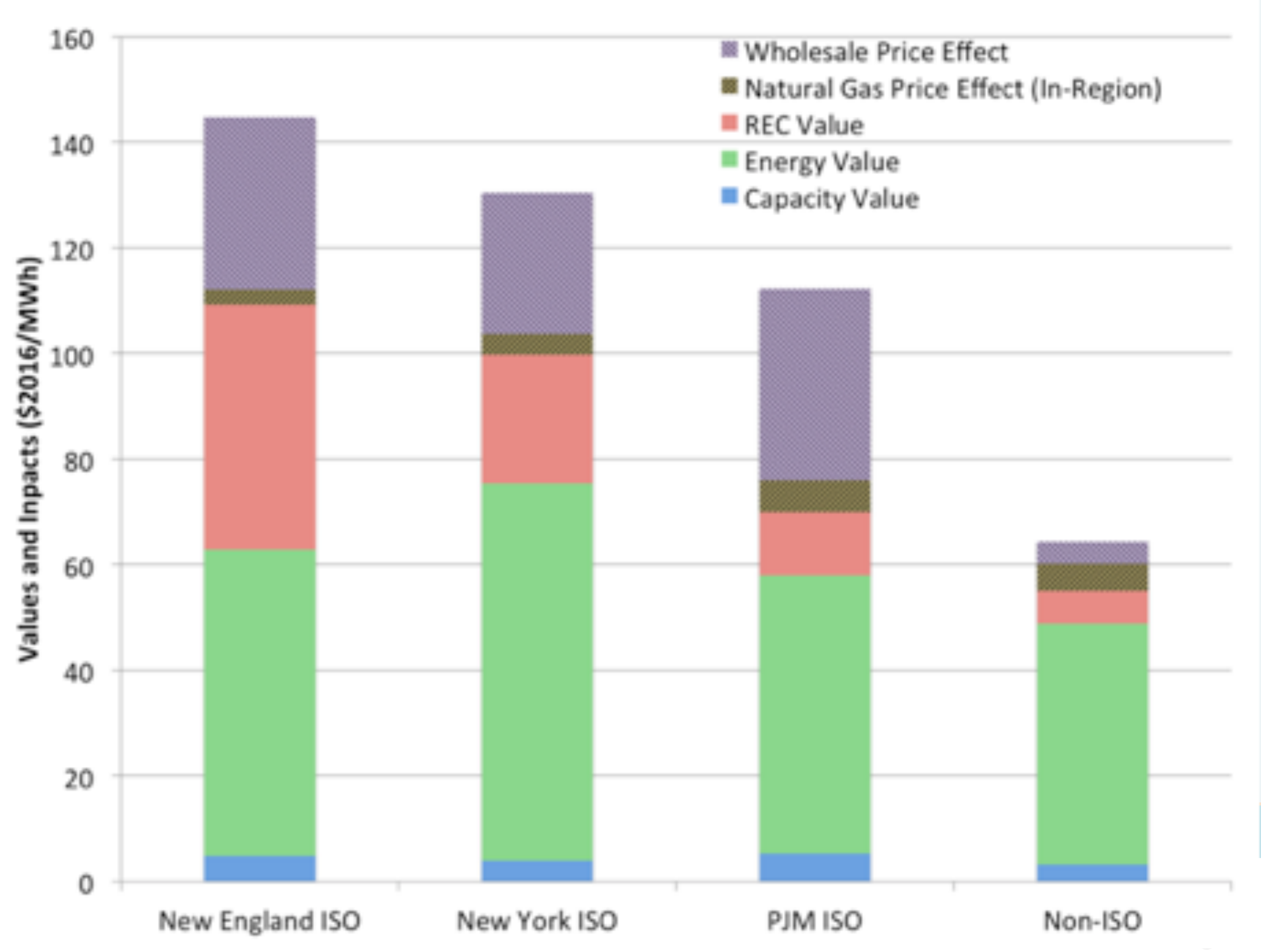
Offshore wind displaces the most gas in the Northeast, resulting in the largest gas savings on a national basis (orange bars).

But the two northeastern regions' share of national savings is the smallest of the four regions, due to lower *total* gas consumption (blue bars).

Similarly represents a transfer of wealth from producers to consumers.



SUMMARY



Wholesale Price Effect
Natural Gas Price Effect (In-Region)
REC Value
Energy Value
Capacity Value
Values and Inpacts ($2016/MWh)
160
140
120
100
80
60
40
20
0
New England ISO
New York ISO
PJM ISO
Non-ISO

ASSESSMENT OF FUTURE TRENDS

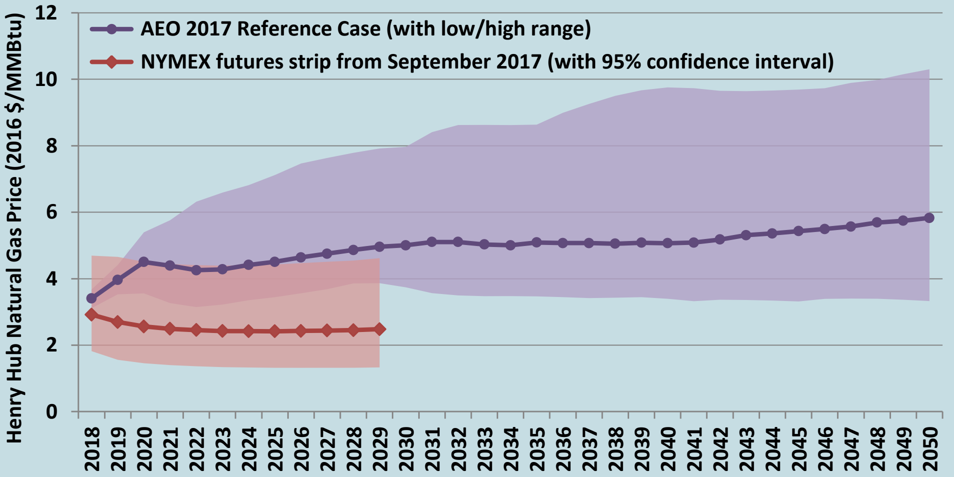
- Energy value
- Capacity value
- REC value
- Air emissions
- Electric and gas price effects

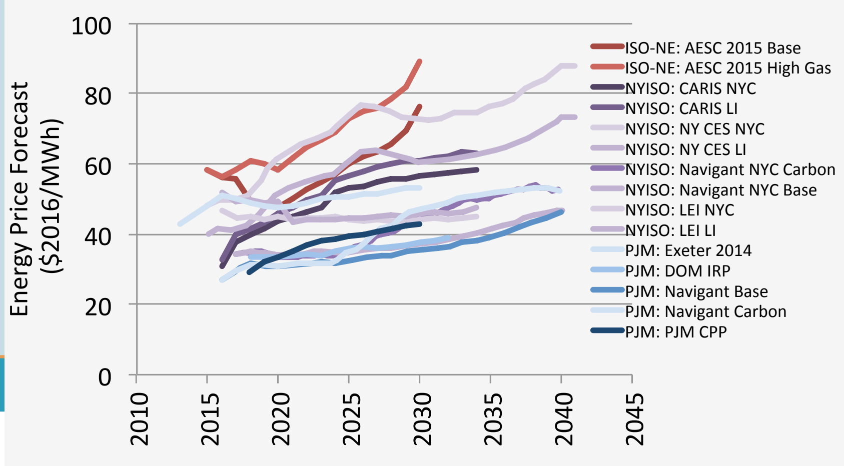
OUTLOOK FOR ENERGY VALUE

Depends on the direction of natural gas prices.

Several projections of electricity prices show significant variation across forecasts, but a general upward trend.

Growth in the share of wind energy could lead to “value factor decline”.

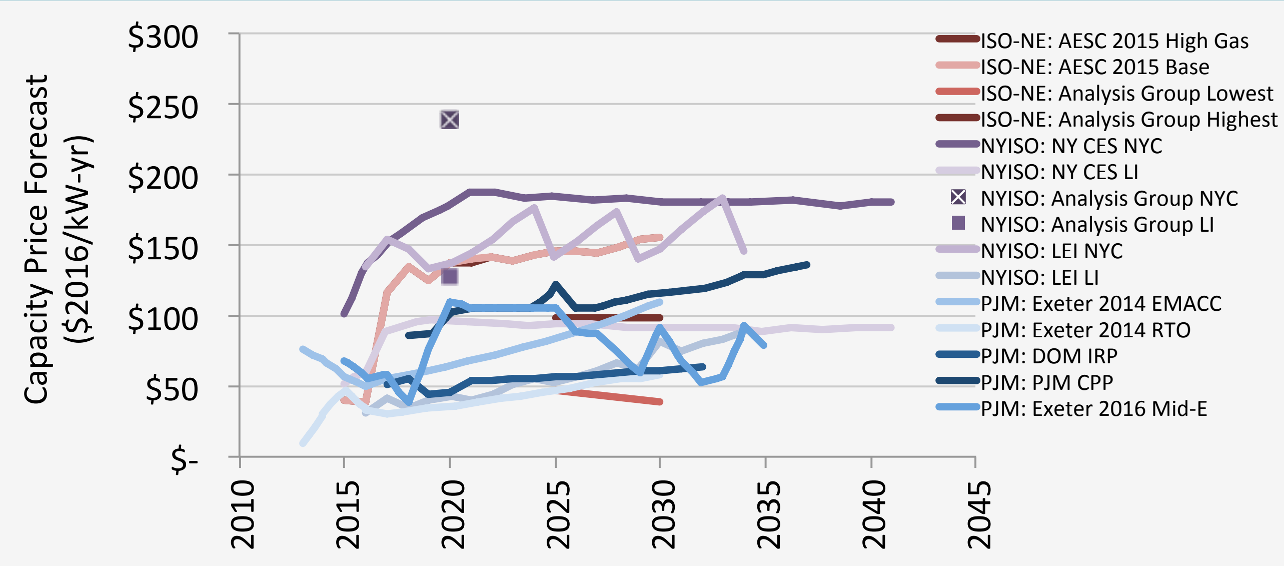




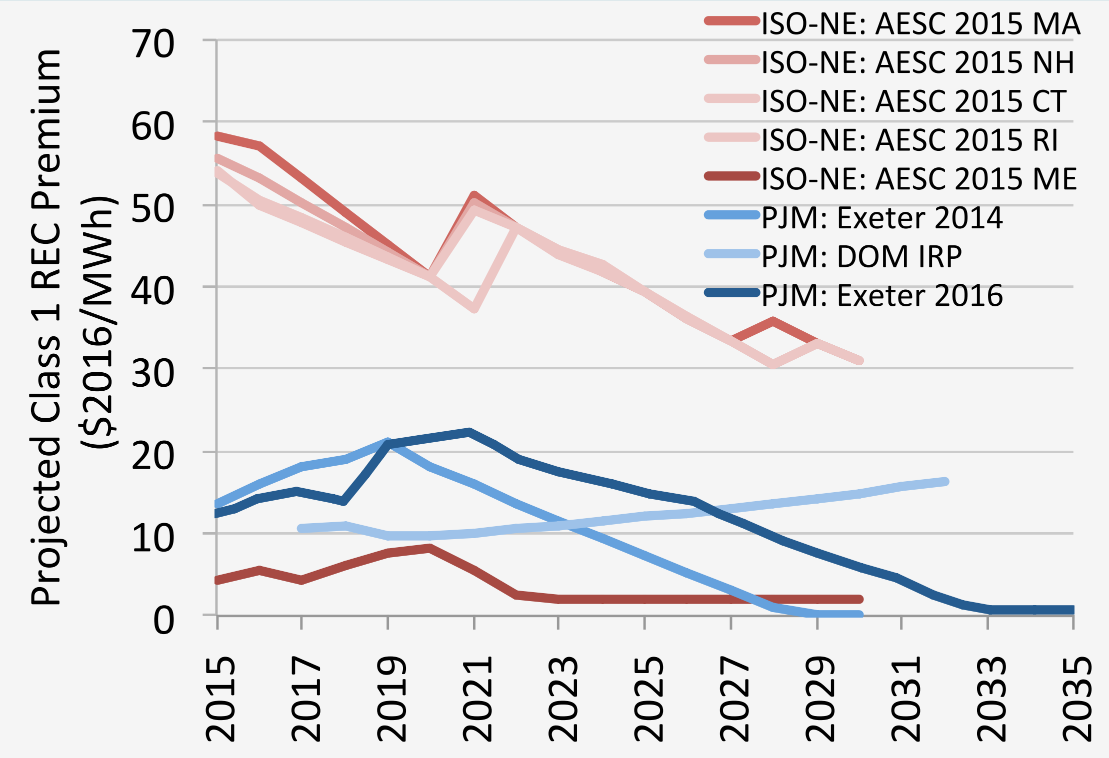
OUTLOOK FOR CAPACITY VALUE

Capacity market prices are expected to increase.

Capacity market reforms may reduce capacity market revenues for wind.



OUTLOOK FOR REC VALUE



OUTLOOK FOR AIR EMISSIONS AND PRICE EFFECTS

Emissions:

Future avoided emissions will likely remain at reduced level unless MATS air quality requirements are removed.

Avoided emissions may also be impacted by future regulatory changes related to CSAPR or to RGGI.

Natural gas prices can affect avoided emissions rates by changing merit order of coal and natural gas plants.

Price Effects:

Expect decay over longer time periods, as supply has time to adjust to lower demand.

Expect lower price response if shale gas continues to flatten the supply curve.

QUESTIONS?

Contact Information

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Acknowledgments

Co-authors: Dev Millstein, Seongeun Jeong, Luke Lavin, Ryan Wiser, Mark Bolinger

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APPENDIX: METHODOLOGICAL DETAILS

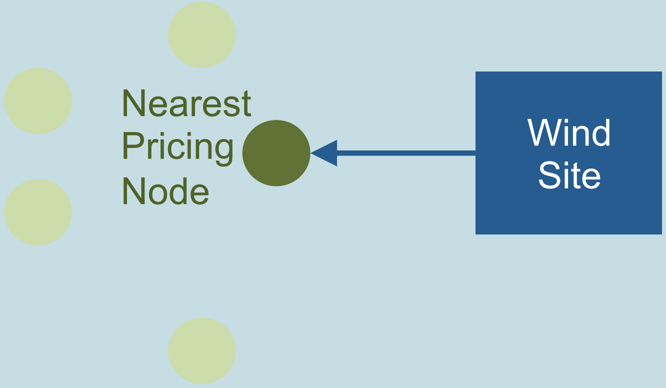
ENERGY VALUE METHODOLOGY

Energy value is calculated as the revenue an offshore wind plant would earn in the energy market by selling its power at the nodal LMP, per unit of wind energy generated. The revenue for each hour is the hourly wind generation multiplied by the hourly real-time LMP.

The hourly LMP accounts for the timing of when energy is cheap or expensive and it embeds the cost of congestion, transmission-level losses and, depending on the region, the compliance cost of various emissions regulations.

For the Non-ISO regions we use the hourly marginal costs reported by the balancing authority (the "system lambda"). Each balancing authority is responsible for determining its method for calculating hourly marginal costs.

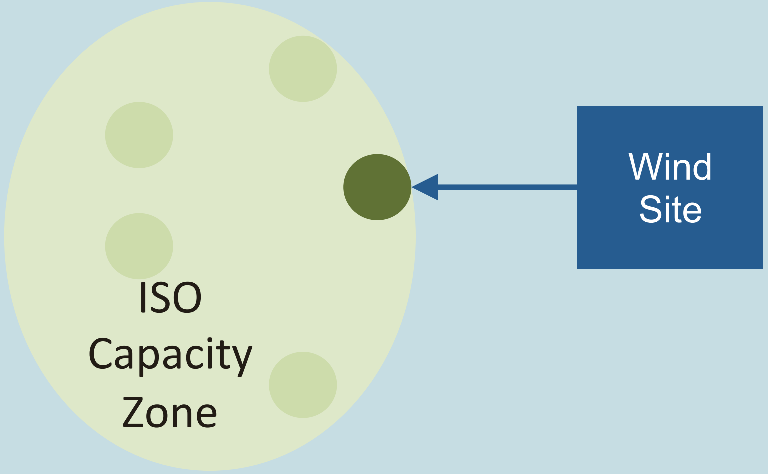
This approach does not account for any costs associated with wind forecast errors or increases in ancillary services. Also, analysis was conducted on a "marginal" basis, estimating the impacts of the first offshore wind projects.



CAPACITY VALUE METHODOLOGY

Capacity value is calculated as the revenue an offshore wind plant would earn in the capacity market by selling its power at the zonal capacity price, per unit of wind energy generated. The amount of capacity that a wind plant can sell is a fraction of its nameplate capacity based on the capacity credit. The rules for calculating the capacity credit of wind plants varies between the ISOs (as described earlier).

Each ISO bases the capacity credit on historical wind production during peak periods. For example, to calculate the 2016 capacity credit for a wind plant in PJM, which uses a rolling average over the past three years, we used wind generation data during the peak for 2013-2015. When there is no historical data available (e.g., we do not have 2006 wind data for the capacity value in 2009), we substitute the average capacity credit over the full 10 years of data.



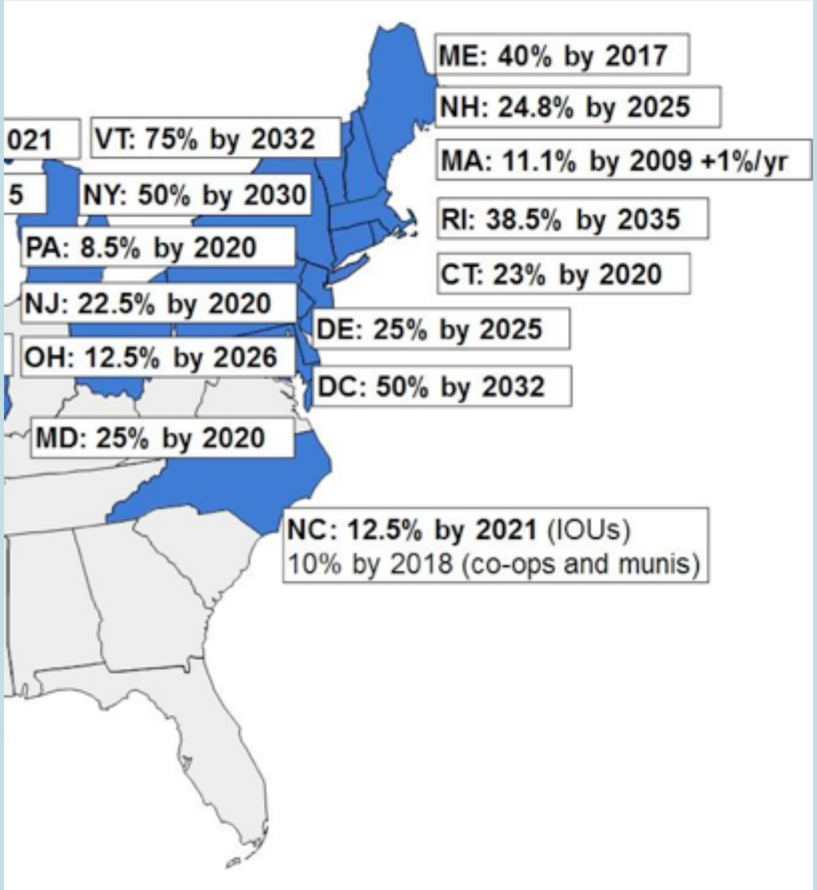
REC VALUE METHODOLOGY

REC value is calculated as the revenue an offshore wind plant would earn by selling Tier 1/Class 1 RECs at monthly REC prices, per unit of wind energy generated.

For states with an RPS, we use the REC prices for the state to which the offshore wind plant interconnects. Spot REC prices are not available for NY or NC, even though these states have an RPS. For NY, we instead use long-term REC prices published by NYSERDA. For NC, we use estimates of RPS compliance costs.

For states whose RPS began after 2007 (DE, RI, ME), we use the highest REC price within the ISO until that state's RPS began.

For VA, which does not have an RPS but is located in PJM, we use the highest REC price available in PJM. For non-ISO states without an RPS (SC, GA, FL), we use national voluntary REC prices.



AVOIDED EMISSIONS METHODOLOGY

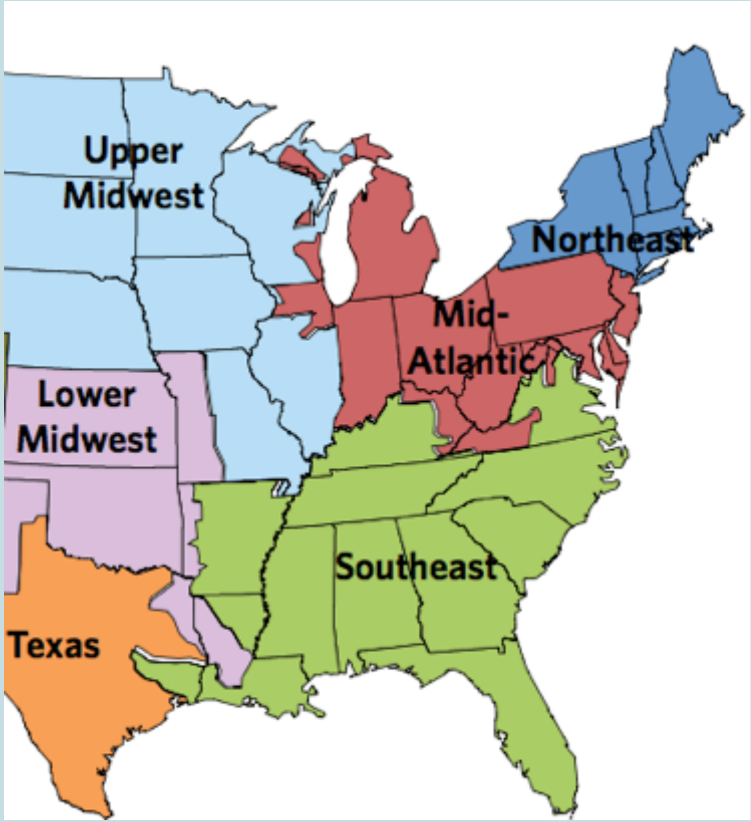
Avoided emissions are calculated based on the emissions rate of the generators that are estimated to be on the margin in each hour. The estimates are based on EPA's AVERT tool, which develops statistical relationships between hourly generator output and net demand.

Unique AVERT models were released by EPA for each year between 2007-2016.

AVERT is used to estimate the emissions (SO_2, NO_x, $PM_{2.5}$, CO_2) that would have been avoided based on an hourly offshore wind power profile developed from all offshore wind sites in each region.

AVERT has three analysis regions along the eastern seaboard:

- AVERT assumes no transfers between regions – only generators within a region are affected by the addition of offshore wind
- AVERT treats all locations within each region as equal



ELECTRICITY PRICE EFFECT METHODOLOGY

Adding a new generator with low marginal costs leads to a near-term reduction in wholesale electricity prices. The wholesale price effect of wind is the difference in the cost to load of purchasing power at spot market prices with and without a wind plant due to these lower wholesale prices.

Studies that use production cost models to simulate power markets with and without wind generally estimate the cost to load as the product of the hourly LMP and the hourly load. Since we do not use such a tool, we estimate the change in prices with a change in supply for each hour using statistical relationships between wholesale prices and demand.

In particular, we estimate the change in the energy component of the LMP as a function of demand and natural gas prices for each year in each ISO. In the Non-ISO region we use the system lambdas instead of the energy component of the LMP.

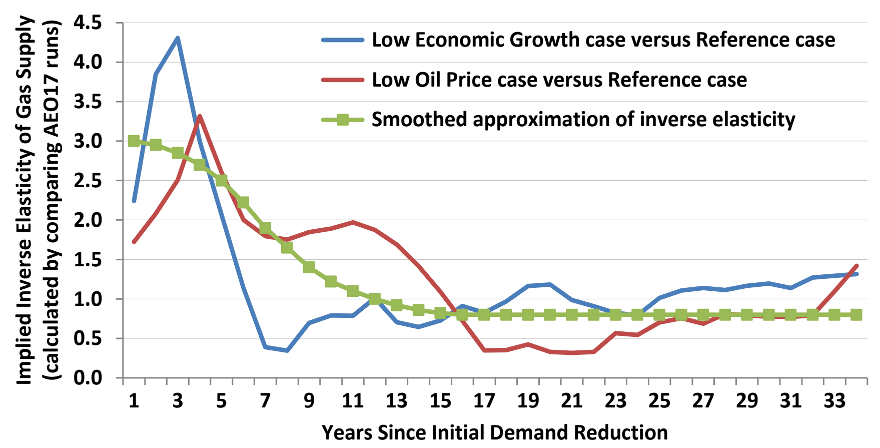
The overall methodology for estimating the relationship between hourly prices and demand is similar to a cost-benefit analysis of a real-time pricing program by Navigant (2011). In contrast to Navigant, we only focus on the energy component of LMPs and do not estimate local congestion components.

Furthermore, we assume that loads in the ISO region use contracts to hedge 60% of their load and vertically integrated utilities in the Non-ISO region hedge 80% of their load. These assumptions are similar to assumptions from other studies (Chernick and Neme 2015), though it is important to note that there is wide variation in assumptions used by different analysts.

NATURAL GAS PRICE EFFECT METHODOLOGY

Using an average hourly offshore wind generation profile from each of its three regions along the eastern seaboard, AVERT estimates the annual reduction in natural gas burn from adding 600 MW of offshore wind to each region. We then translate that MMBtu reduction into a % reduction in national gas demand in the year in question, and apply a first-year (i.e., no decay) inverse elasticity of supply of 3.0 (see figure) to arrive at the corresponding % reduction in national average wellhead prices. We apply the % wellhead price reduction to average wellhead prices in the year in question to arrive at the corresponding $/MMBtu price reduction. Total dollar savings nationally are the product of the $/MMBtu price reduction and total national gas consumption post-wind. Dividing total dollar savings by the annual MWh of offshore wind yields national $/MWh-wind savings.

In-region dollar savings are the product of the national $/MMBtu price reduction and total in-region gas consumption post-wind. Dividing in-region dollar savings by the annual MWh of offshore wind yields in-region $/MWh-wind savings.



ATMOSPHERIC STABILITY AND WAKE LOSSES

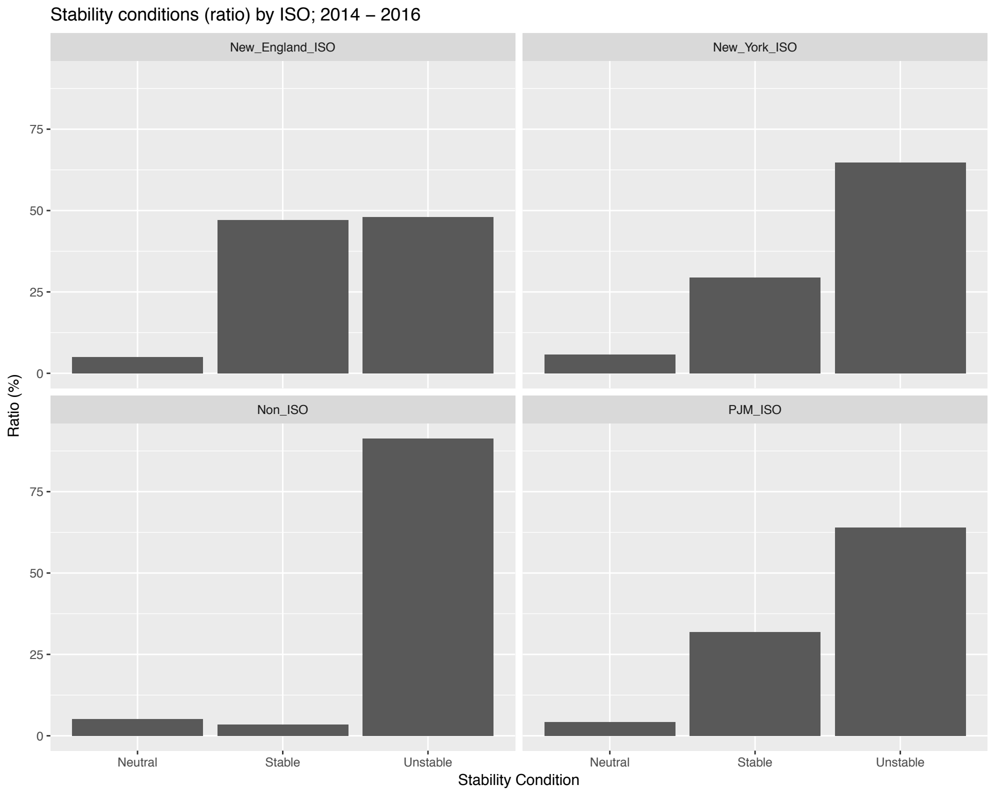
The supplemental results on wake losses examines the potential impact on the value of offshore wind if unstable conditions (when wake losses are lower) are correlated with times of high value.

Here we show the percentage of time that the atmosphere is considered Neutral, Stable, or Unstable based on the Monin−Obukhov Length for the median value site in each region.

The assumption that the atmosphere is stable half of the year is reasonable for New England ISO.

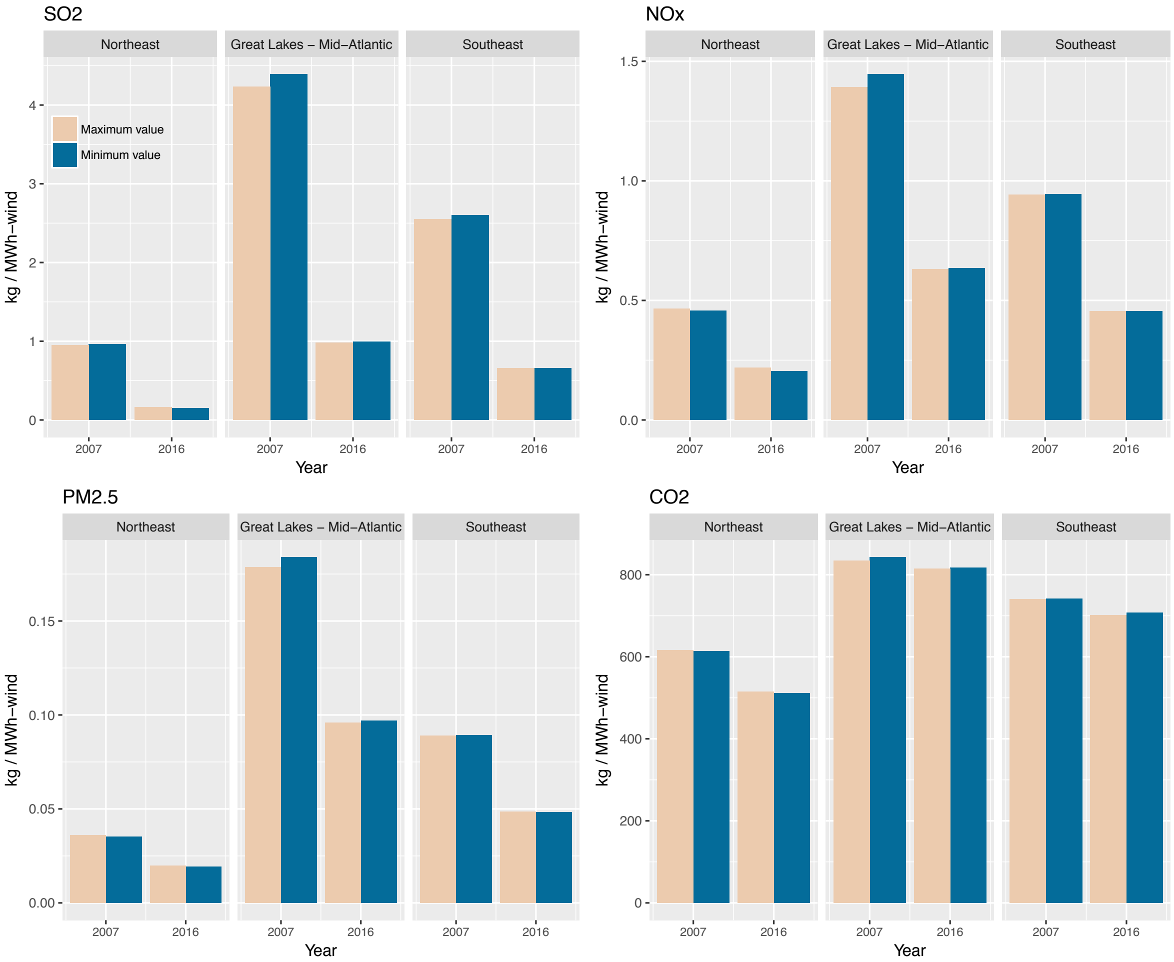
Regions further to the south have unstable conditions more frequently.

These trends across regions are corroborated by a second measure of atmospheric stability, the Boundary Layer Height.



AVOIDED EMISSIONS ARE INSENSITIVE TO OFFSHORE WIND PROFILES

We calculated the avoided emissions of offshore wind using the wind generation profile for the site in each region that had the highest and lowest normalized total value. The figure demonstrates that the avoided emissions are not sensitive to the choice of wind generation profile. We therefore use the average wind profile in each region, rather than the wind profile at each individual site, when calculating the avoided emissions of offshore wind.



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