Wind energy saves consumers money during the polar vortex

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Introduction

Wind energy saved electricity users in the Mid-Atlantic and Great Lakes states at least $1 billion during the polar vortex event in early January 2014.

By diversifying America's energy mix, wind energy improves electric reliability and protects consumers from energy price spikes. While wind energy always provides these benefits, they can become particularly pronounced when the electric grid is stressed.

On January 6th and 7th, 2014, frigid Arctic air blanketed the Eastern U.S. when the "polar vortex" that normally holds cold air near the North Pole briefly weakened. The extreme cold snap, which became known as the "polar vortex" event, caused unusually high demand for electricity as well as for natural gas for both heating and electricity generation. In addition, extremely low temperatures contributed to unexpected failures at many power plants, due to equipment breaking and shortages of fuel.

Driven by high demand and low supply, electricity and natural gas prices rose to dozens of times their normal levels in many regions. The Mid-Atlantic and Great Lakes states were particularly hard hit by these abnormally cold temperatures and the resulting energy prices spikes.

There and in other regions, wind energy provided large quantities of critical electricity supply when it was needed most, keeping the lights on and reducing the impact of these price spikes. Our analysis quantified the savings wind energy provided to Mid-Atlantic and Great Lakes consumers on January 6th and 7th, 2014, by calculating how much more electricity prices would have increased had the region's wind generation not been online. Using hourly grid operator data, fuel price information, and a detailed representation of the characteristics of every power plant in the region, our analysis quantified how wind energy kept electricity price spikes in check.

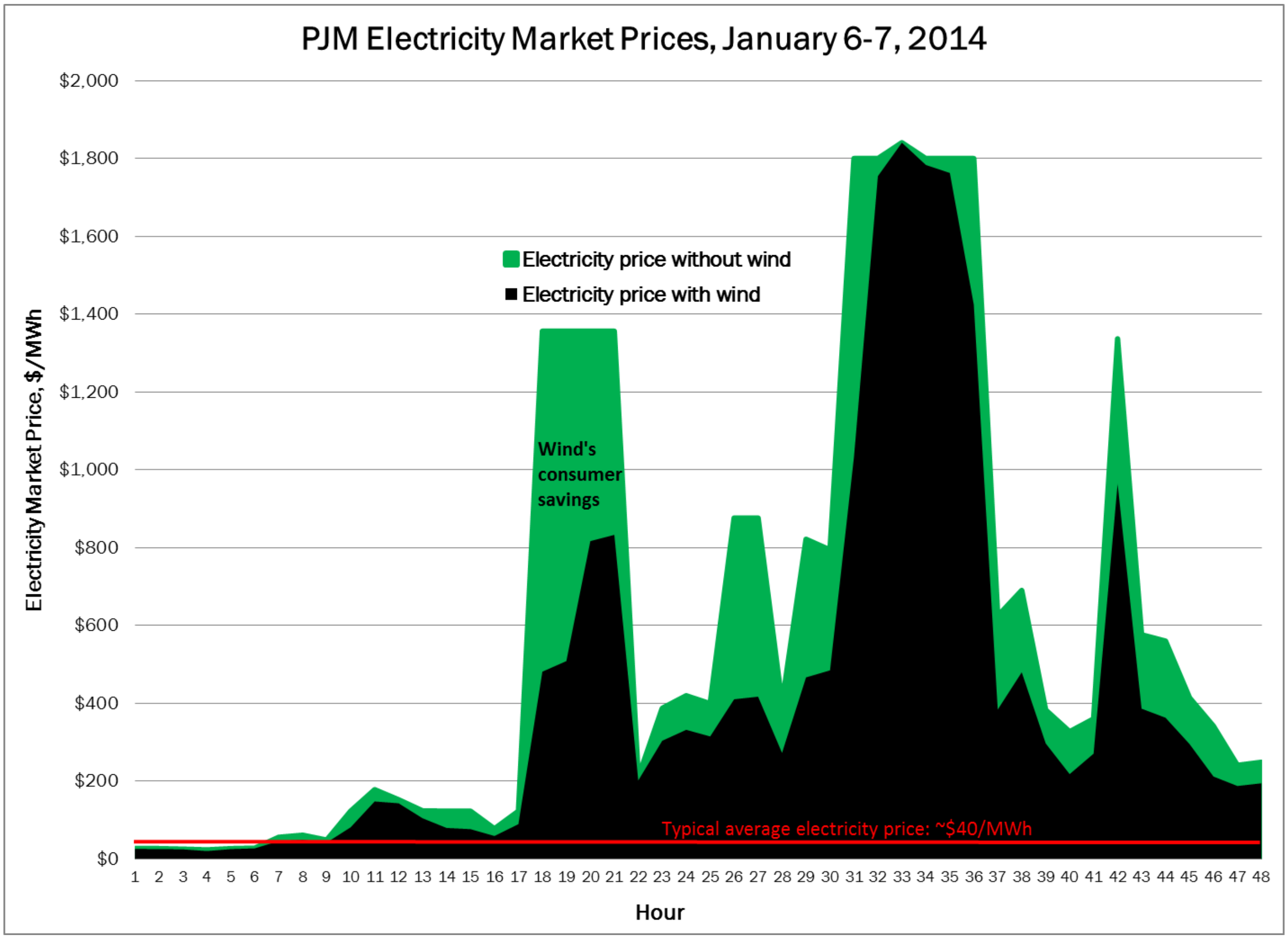
Wind energy's consumer benefits stem from wind energy's fuel price stability. Wind is one of the few energy sources that offers perfect fuel price stability that can be locked in up front, as wind's fuel cost will always be zero. For all other major conventional sources of electricity, fuel prices cannot be locked in for the long term and are often set by the spot market. The costs of these fuel price increases and risk are passed directly on to consumers through their electric bills. In contrast, wind energy is more like a fixed-rate mortgage, locking in the fuel price for the life of the power plant.

As shown in the table below, wind energy creates these large consumer benefits by displacing the most expensive, least efficient, and most volatilely-priced power plants with a fixed-priced, zero-fuel-cost, zero-emission energy source. All of these benefits are purely market driven, occurring entirely because zero-fuel-cost wind energy is used to displace more expensive forms of energy.

	Wind energy	Power plant displaced by wind energy
Cost	**Zero fuel cost**	Highest fuel cost
Fuel price stability	**Fixed price**	Volatilely-priced
Pollution	**Zero emissions**	Least efficient

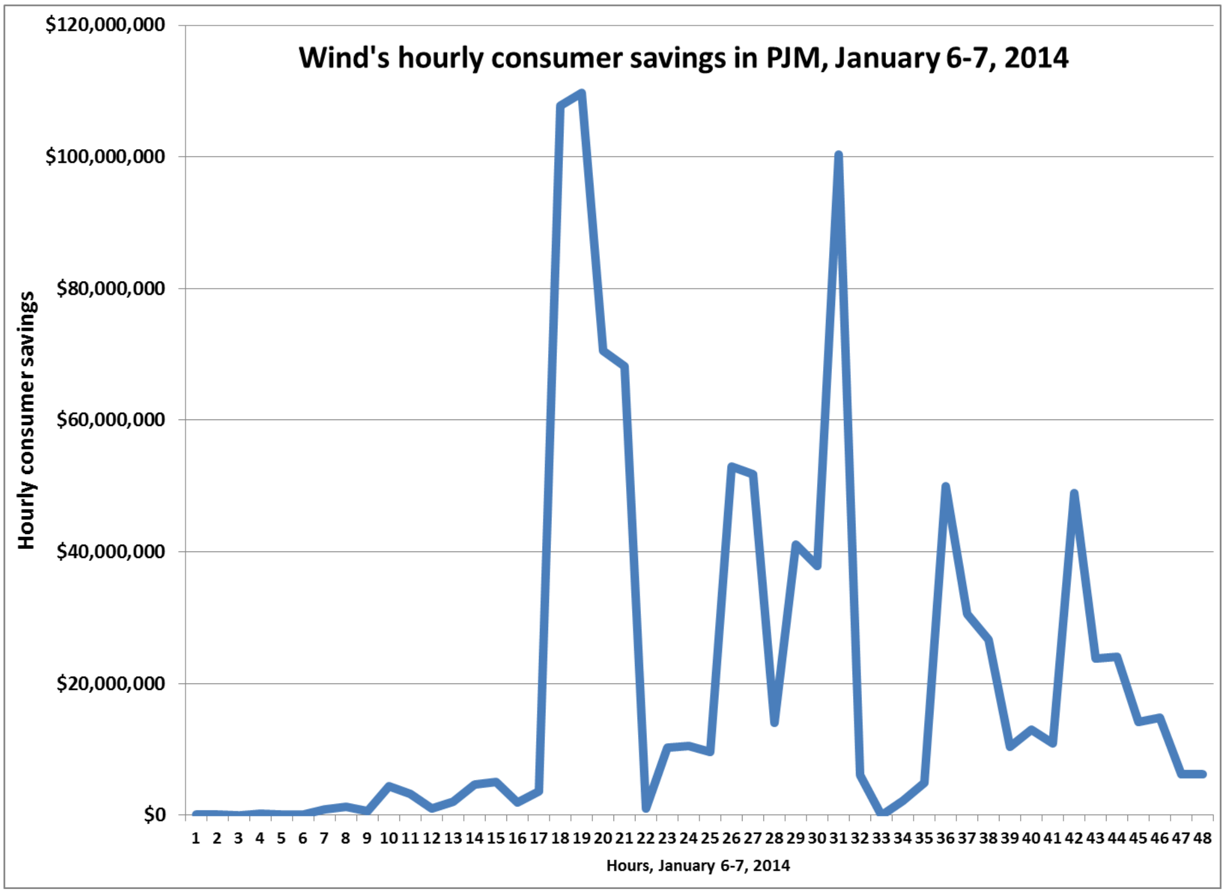
Results

Wind energy protected Mid-Atlantic and Great Lakes consumers from extreme price spikes during the polar vortex event in early January 2014, saving consumers over $1 billion on their electric bills. The black area in the following chart shows the actual power prices experienced in the electricity market that spreads across 13 Mid-Atlantic and Great Lakes states, known as PJM.[1] As indicated by the red line at the bottom, these prices greatly exceeded typical PJM power prices. However, the green area shows that power prices would have spiked much higher had PJM not had abundant supplies of wind energy throughout this critical time period.



[1] PJM operates the electricity grid and market for all or part of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and the District of Columbia

The shaded green area in the chart above shows the amount by which wind energy reduced the electricity price spikes. These reduced electricity prices accrue to all of the electricity that was purchased by consumers in the market, not just the wind energy that was purchased. Because total electricity consumption was very high, wind's consumer savings for those two days alone total over $1 billion, as shown in the chart below.



The following table summarizes wind's consumer savings for those two days, and also shows how power plant outages and gas price spikes caused electricity prices to reach record levels in PJM.

Day	Total Wind Consumer Savings	Average Wind Generation (MW)	Weighted Average Electricity Market Price	Average Power Plant Outages (MW)	Weighted Average Delivered Gas Prices ($/MMBtu)
Jan 6th	$407,766,567	3,280	$500/MWh	30,239	$17.26
Jan 7th	$600,779,296	1,803	$1,178/MWh	36,551	$9.58

Background

In early January 2014, Arctic air inundated much of the Eastern U.S. when the "polar vortex" that normally keeps cold air contained near the North Pole briefly weakened.[2] The extreme cold caused unusually high demand for electricity as well as for natural gas for both heating and electricity generation. High demand led to extremely high prices for both electricity and natural gas, with high natural gas prices translating into high electricity prices because most electricity market prices were being set by natural gas power plants. In addition, extremely low temperatures contributed to unexpected failures at many power plants, due to equipment breaking and shortages of fuel.[3] For example, at 7 PM on January 7th, 40,200 MW of generating capacity, 22% of PJM's entire generation fleet, was unavailable due to unexpected outages.[4]

Wind energy provided similar benefits during cold snaps in other regions in early 2014:

- Early on January 6, the Nebraska Public Power District met record winter electricity demand with wind providing about 13% of its electricity. The utility explained that "Nebraskans benefit from NPPD's diverse portfolio of generating resources. Using a combination of fuels means we deliver electricity using the lowest cost resources while maintaining high reliability for our customers." The utility also noted that "NPPD did not operate its natural gas generation because the fuel costs were up more than 300 percent over typical prices."[5]
- On January 7, wind output was very high when the New York and New England grid operators faced record winter demand.[6] New England has previously benefited from very high wind output when facing extreme demand that causes electricity and natural gas prices to spike.[7]
- On January 22 and 23, PJM electricity and natural gas prices skyrocketed to 10-50 times normal due to extreme cold and unexpected outages at many power plants.[8] Wind output was again above 3,000 MW, saving consumers millions.
- As "a shortage of natural gas triggered by extreme cold weather" affected California on February 6, 2014, wind energy provided the state with around 2,000 MW at the time of peak demand, with wind output above 2,500 MW for most of the rest of the evening.[9] The state grid operator noted that this wind output allowed it to avoid calling an energy emergency alert.[10]

These events are a powerful reminder that wind energy plays a critical role in diversifying our energy mix, improving energy reliability and reducing energy costs for homes and businesses. Diversity inherently makes the power system more reliable by protecting against the unexpected failures that afflict all energy sources from time to time. All energy sources experienced unexpected outages during the cold snaps in January 2014. While wind energy output does change with the wind speed, such

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[2] http://www.climate.gov/news-features/event-tracker/wobbly-polar-vortex-triggers-extreme-cold-air-outbreak
[3] http://www.nerc.com/pa/rrm/January%202014%20Polar%20Vortex%20Review/Polar_Vortex_Review_29_Sept_2014_Final.pdf
[4] http://www.pjm.com/~/media/documents/reports/20140509-analysis-of-operational-events-and-market-impacts-during-the-jan-2014-cold-weather-events.ashx,page 24
[5] http://www.nppd.com/2014/nebraska-customers-set-time-winter-peak-nppd/
[6] http://www.nyiso.com/public/webdocs/media_room/press_releases/2014/NYISO%20-%20Frigid%20Temperatures%20from%20Polar%20Vortex%20Drive%20Record%20Winter%20Demand%20-%2001_09_14%20-%20FINAL.pdf; http://www.iso-ne.com/isoexpress/web/reports/operations/-/tree/daily-gen-fuel-type
[7] http://green.blogs.nytimes.com/2013/02/17/could-wind-power-cool-new-englands-price-fever/
[8] http://www.nrc.gov/reading-rm/doc-collections/event-status/reactor-status/2014/20140122ps.html
[9] http://www.caiso.com/Documents/ISOissuesStatewideFlexAlert.pdf
[10] SNL Energy article, Christine Cordner, "CAISO: Wind, demand response helped avoid February emergency alert," March 21, 2014

changes occur far more slowly than the unexpected outages that frequently occur at large conventional power plants. Moreover, changes in wind energy output are predictable using weather forecasting, while conventional power plant failures are not, making them far more difficult and costly for grid operators to accommodate.[11]

Wind energy benefits consumers through at least six distinct mechanisms. While wind energy always provides these benefits, they can be particularly pronounced when electricity markets are facing shortages and price spikes.

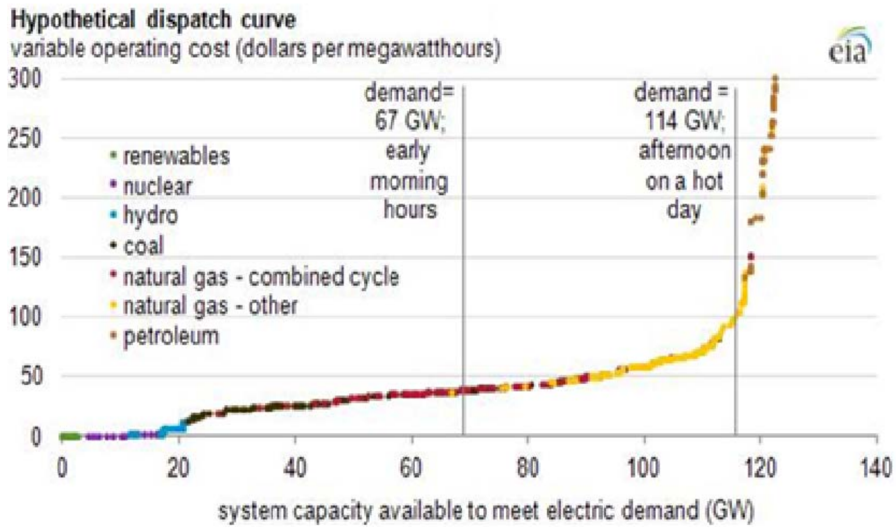
The consumer benefits of wind energy

1. Wind reduces the cost of producing electricity. Zero-fuel cost wind energy directly displaces the output of the most expensive and least efficient power plants that are currently operating. Like the functioning of almost any market, electricity market operators rank power plants based on their cost of producing an incremental amount of electricity. They then start by using the least-cost power plants first, and then move up the supply curve until they have enough electricity to meet demand. The power plant rank order is based on the cost for that plant to produce an incremental amount of electricity, so only fuel costs and variable operations and maintenance costs are considered. As a result, wind energy and other low fuel cost resources are always used first, and they are used to displace the most expensive power plants that otherwise would have operated. Because that is almost always the least efficient fossil-fired power plant, adding wind energy greatly reduces fossil fuel energy costs and pollution.

2. Wind energy protects consumers by reducing the impact of electricity price spikes. The reduction in the need for conventional generation described above allows demand to be met by conventional generators with lower fuel cost, and therefore a lower cost of producing electricity. This reduces the market clearing price for all electricity purchased in the market. This is known as the "merit order" effect because it allows the market operator to move down the merit order, or supply curve, to use generators with a lower marginal production cost to meet demand, resulting in a lower market clearing price. Wind energy has a low marginal production cost because it has zero fuel costs.[12] This drives down the market price for all electricity that is being purchased in the market, not just the wind electricity, as the market price for all electricity purchasers is set by the last and most expensive power plant that was chosen to operate.

As an example, the following chart shows a hypothetical electricity supply curve for a fictitious grid operating area.[13] Adding low marginal cost generation like wind to the left side of the curve will push the supply curve out to the right, allowing electricity demand to be met by a lower cost power plant and therefore reducing the price of electricity. Because some parts of the generation supply curve can be quite steep, particularly during shortage periods like PJM and other areas experienced in early 2014, even a modest amount of additional supply can greatly benefit consumers.

[11] For analysis of the relative integration costs for wind generators versus conventional generators, using data from the Texas grid operator, see http://aweablog.org/blog/post/fact-check-winds-integration-costs-are-lower-than-those-for-other-energy-sources
[12] Wind reduces electricity prices because it has no fuel cost; the myth that wind reduces market prices because it receives the renewable Production Tax Credit (PTC) was debunked here: http://awea.files.cms-plus.com/FileDownloads/pdfs/AWEA%20white%20paper-Cutting%20through%20Exelon%27s%20claims.pdf Other low-fuel-cost forms of energy, such as nuclear, have the same impact on market prices. Because wind almost never sets the market clearing price, it has the same impact on markets regardless of whether it offers a price that includes the value of the PTC. While the PTC is important for driving new wind development, the PTC is almost never reflected in market prices.
[13] http://www.eia.gov/todayinenergy/detail.cfm?id=7590



3. Wind energy reduces pollution. Pollution from fossil-fired power plants harms public health and the environment in a number of ways, and these costs are not currently reflected in electricity market prices. These air pollutants include health-harming sulfur dioxide, smog-forming nitrogen oxides, and the greenhouse gas carbon dioxide. Fossil fuel consumption at power plants also causes air pollution from mercury and other toxins, water use, water pollution, and other impacts.

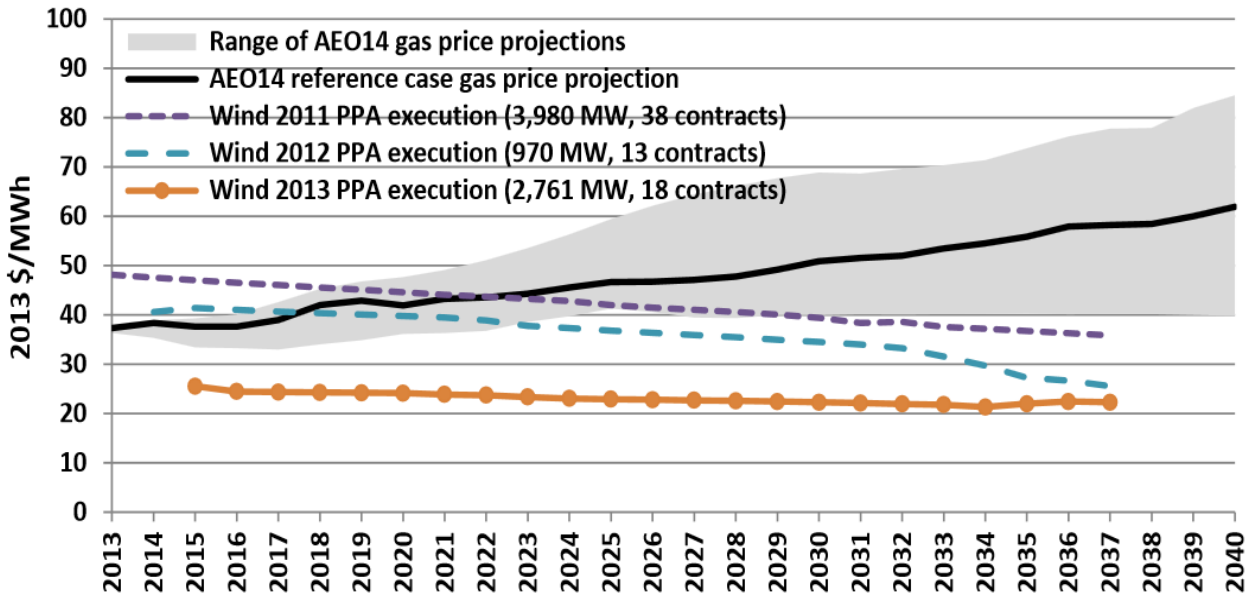
4. Wind energy hedges against fuel price volatility. Wind energy also protects consumers from uncertainty about the price of fossil fuels. The risk of fossil fuel price volatility makes consumers worse off, and one of the most effective tools for reducing that risk is by diversifying the energy mix with zero fuel cost wind energy. Wind energy helps to hedge against volatility in the price of fossil fuels much like a fixed-rate mortgage protects consumers from interest rate fluctuations. In the following chart, the grey area indicates the large uncertainty about future fuel prices. The cost of this uncertainty is distinct and in addition to the cost of the expected increase in fuel prices, indicated by the black line in the chart. Wind energy provides this benefit at all times,[14] though the consumer savings are particularly pronounced during periods of extreme fuel price spikes.

5. Fixed-price wind energy becomes an even better deal as other fuels increase in price over time. Even if fossil fuel prices were known with perfect certainty, their prices are still expected to increase over time and those costs are borne by consumers. Almost all of a wind plant's costs are fixed up front, and many wind power purchase agreements remain at the current cost for the life of the contract. In contrast, the cost of conventional generation changes significantly based on fuel costs, and these costs are passed on to consumers. While the cost of the uncertainty itself was accounted for above, one must also account for the fact that fossil fuel prices are expected to increase, and that this will tend to increase wind's production cost savings in the future.

The following chart from a recent report by the Department of Energy and Lawrence Berkeley National Laboratory also shows how the value of wind energy increases as fuel prices increase over time.[15] Wind

[14] http://emp.lbl.gov/publications/revisiting-long-term-hedge-value-wind-power-era-low-natural-gas-prices, http://emp.lbl.gov/publications/accounting-fuel-price-risk-using-forward-natural-gas-prices-instead-gas-price-forecasts
[15] http://emp.lbl.gov/sites/all/files/2013_Wind_Technologies_Market_Report_Final3.pdf

energy's costs are largely fixed at their current level for the life of the power purchase agreement and can even decrease due to inflation (as seen in the purple, teal and orange lines), while the cost of natural gas generation grows over time as the price of natural gas increases (as seen in the black line with the grey uncertainty area). When evaluating the costs and benefits of fixed-price wind energy, one must factor in the costs and risks of future fuel price increases for the alternatives, just as one would when comparing fuel efficiency to determine which car to purchase.



6. Wind reduces consumer natural gas prices. Through the same supply and demand mechanism described above, wind energy also reduces prices in fossil fuel markets by reducing fossil fuel demand, providing savings for all fossil fuel users. During these times of peak demand, wind energy was primarily displacing natural gas use at natural-gas fired power plants. Many areas in the Eastern U.S. were at or near record natural gas prices due to weather-driven demand for natural gas for building heating as well as electricity generation. Because the natural gas supply curve is also quite steep during times of peak demand, and because the market price applies to all transactions in the market, wind energy produced large savings for all natural gas users by driving down the price of natural gas. Because the market price applies to all transactions in the market, including gas used for building heating or industrial purposes, wind energy can produce large savings for all natural gas users by driving down the market price. This analysis did not attempt to quantify those savings, which would be in addition to the electricity market consumer savings identified above.

For analysis of how wind energy also provides these benefits during periods of normal grid operations, see our analyses showing how wind provides billions of dollars in benefits to consumers in Texas[16] and the Lower Plains.[17]

[16] http://awea.files.cms-plus.com/ERCOT%20report%2011-7FINAL.pdf
[17] http://awea.files.cms-plus.com/SPP%20report%20November%202014%20final.pdf

Methodology

Hourly wind generation, electricity demand data, and market price data for January 6 and 7, 2014, were obtained from PJM; these data are reproduced in the Appendix.[18] PJM generation supply curve data, showing the marginal production cost and equivalent available capacity of every operational PJM generator, was obtained from industry data source SNL Energy. Mothballed, long-term out-of-service, retired, planned, and under construction generation was removed from SNL's supply curve. Wind capacity was also removed from the supply curve for this step, as actual hourly wind generation is incorporated into the model later in our analysis.

The normal PJM supply curve was adjusted to account for gas price changes and generator outages that occurred on January 6 and 7, 2014. A PJM Market Monitor report supplied gas price data in a graph showing the cost of delivered natural gas for Eastern and Western PJM power plants.[19] While Monitoring Analytics was unable to release the exact data, estimates of delivered gas prices were derived from the graph. By weighting the regional prices, we were able to create a composite PJM fuel price for each day that was used to create the supply curve for each time interval.

The second critical input is generator outage data, which was sourced from a report on the polar vortex released by PJM.[20] The report listed data on outages at the PJM-wide level. The outage information was further broken down by generator type, and gave three snapshots, one on January 6 and two on January 7. From the outage data, the availability factor for each generator type[21] was pro-rata applied to all generators of that type by dividing the generator type outages by the PJM wide capacity for that type of generator. This process, along with incorporating the daily gas price information, was then repeated for all three time periods to create three separate supply curves.

The total non-wind generation for each hour, which is used to determine the market clearing price in both the wind case and the hypothetical no wind case, was then calculated by subtracting wind generation. In the hypothetical no wind case, the non-wind generation was set equal to the total demand (reflecting that additional conventional generation equivalent to the amount of actual wind generation would have been used in the absence of wind generation), while in the wind case the non-wind generation was calculated as the total generation in that hour minus the wind generation in that hour.

A lookup function for the generation supply curve was used to calculate what the wholesale electricity market clearing price would have been in each hour under each case, by moving up the supply curve to find the marginal production cost for the last generator that needed to run to meet demand net of wind generation. The marginal production cost of the last generator sets the market clearing price. The difference in prices between the wind and no-wind cases, multiplied by the total demand in that hour and summed for all hours, is the consumer price reduction benefit provided by wind.

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[18] http://www.pjm.com/markets-and-operations/ops-analysis.aspx,http://www.pjm.com/markets-and-operations/energy/real-time/lmp.aspx, http://www.pjm.com/~/media/documents/reports/20140509-analysis-of-operational-events-and-market-impacts-during-the-jan-2014-cold-weather-events.ashx

[19] Page 128 http://www.monitoringanalytics.com/reports/PJM_State_of_the_Market/2014/2014q1-som-pjm.pdf

[20] Page 2 http://www.pjm.com/~/media/documents/reports/20140109-january-2014-cold-weather-peaks-and-generator-outages.ashx

[21] Diesel and combustion turbine generators were reported in aggregate, so we assumed that the outages were distributed between the two proportional to generation capacity.

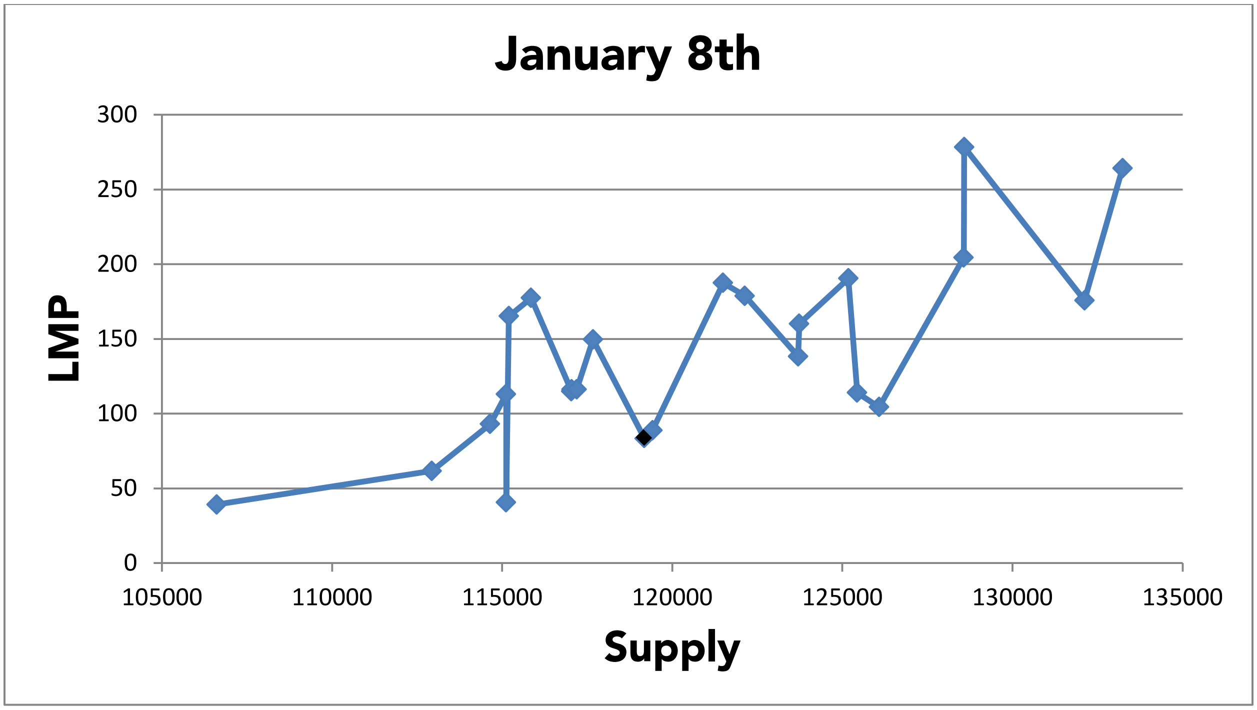
This calculated benefit is gross consumer savings, as it does not take into account utilities' cost of purchasing wind through long-term Power Purchase Agreements (PPAs) outside of the wholesale electricity market. Because it was not possible to determine which wind projects were producing during this time period and therefore what $/MWh price was being paid for produced wind energy, and because PPA terms are not always made public, this cost was not accounted for in the analysis. However, a ballpark estimate indicates that such costs would account for less than 1% of the gross consumer benefits provided by wind energy during this time period.[22]

Our analysis also took account of the fact that electricity market prices were not uniform across PJM in all hours of January 6-7. Electricity prices in PJM's primary wind-producing areas were around 4% lower than the average prices for the entire PJM footprint, on an hourly wind generation-weighted basis. As a result, the gross consumer benefit number of $1.007 billion reported above had already been reduced by 4% (from $1.045 billion) to conservatively account for the fact that wind's price reductions may have been slightly smaller because the wind supply was concentrated in areas that had slightly lower than average prices.

Our analysis was also conservative in its treatment of wind's consumer price reduction during the four hour period of 6-10 PM on January 6, 2014. Our model indicated that, without wind, electricity demand would have likely exceeded the available generating capacity during that time period. To be conservative, given that it is unclear precisely how fuel prices and generator outages had altered the shape of the supply curve during those hours, we assumed that conventional generators would have been able to meet demand during those hours even without wind. This resulted in the last available generator setting the market clearing price of $1,356/MWh. However, had demand exceeded supply, demand response would have potentially been called up, likely setting the market clearing price at $1,800/MWh. Assuming this would have occurred would have increased wind energy's calculated consumer benefits by hundreds of millions of dollars.

An adjustment to our approach was required because in some hours actual market prices did not correspond with the expected upward slope of an electricity supply curve, as shown below. This likely occurred because of nodal gas price fluctuations not being captured between the daily reports of fuel prices, hourly generator outages not being accurately captured by the 12-hour interval generator outage date, generator ramping limits, transmission limits, and other constraints that do not show up in the data that is publicly available. To correct for this, we created a lookup function that used actual hourly market prices to identify the point on the generation supply curve that should have corresponded to that market price, and assumed that wind generation lowered price by moving the market down the supply curve from that point. We determined this was the best approach, as preserving the general shape of the supply curve while also ensuring that the results were consistent real-world LMP data were the two most important considerations, while alternative methods would not have preserved both factors.

[22] 2,550 MW of average hourly wind production on January 6-7, times 48 hours, times $60/MWh rough estimate for average price of cumulative PJM wind PPAs = $7.3 million in cost. This would reduce wind energy's net consumer benefit to around $1 billion.



To validate this method, we additionally used an alternate method of calculating wind's consumer benefits. The results of that analysis are very similar to the results obtained using the above methodology, providing additional support for the results of our method. In the alternate method, the observed impact of hourly changes in electricity demand on electricity market price was used to infer the slope of the generation supply curve in each hour. That slope was then used to calculate the consumer savings wind energy provided in each hour. This method was used because a decrease in electricity demand has the same impact on market prices as an identically-sized increase in wind generation. Using this method, wind's total consumer benefits in all hours in which the supply curve was found to slope upward were calculated at $801 million for the two day period.

Because a supply curve cannot slope downward, several potential methods were explored for filling in the 14 out of 48 hours in which the supply curve did not appear to slope upward. Using the average of the supply curve slope across all hours (including negative slope hours) in place of the slope values for downward-sloping hours produced an estimated total for wind's consumer savings of $987 million. Using the average for all upward-sloping hours produced an estimated total for wind's consumer savings of $1.167 billion. Interpolating the average slope for the two adjacent hours with a positive slope produced an estimated total of $1.321 billion. All of these results were very close to the $1 billion in consumer savings found under our initial method, lending additional support to that method and result.

Appendix

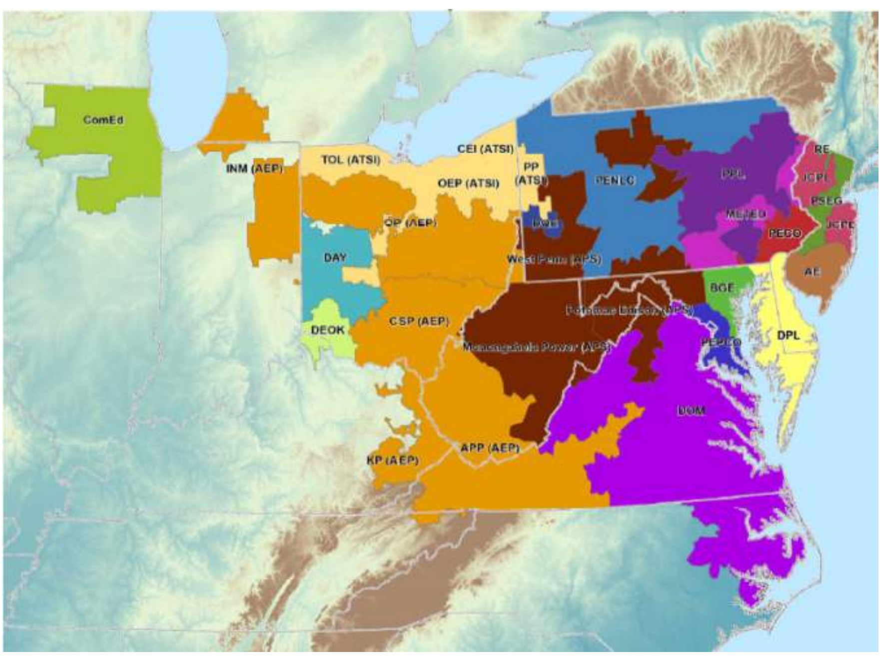
PJM hourly wind, demand, and price data

Date/Time	PJM Average Power Price	PJM Electricity Demand	PJM Wind Generation
6-100	26.121081	85497	3976.965
6-200	25.765411	83511	3866.902
6-300	25.044994	82631	3648.733
6-400	20.770097	83277	3639.055
6-500	25.650717	85369	3427.755
6-600	27.63005	90884	3302.677
6-700	46.381305	99318	3210.341
6-800	49.226979	105679	3327.634
6-900	42.480832	107237	3364.96
6-1000	81.652214	108896	3387.159
6-1100	148.173373	110735	3405.508
6-1200	143.299272	111974	3326.078
6-1300	104.89542	112676	3358.304
6-1400	80.121071	112609	3423.495
6-1500	76.894722	112263	3437.564
6-1600	59.41488	113124	3352.604
6-1700	89.692063	117139	3234.667
6-1800	481.590549	125786	3213.113
6-1900	508.742267	130518	3034.43
6-2000	817.059974	131047	2863.939
6-2100	833.085769	130429	2810.607
6-2200	201.987208	128819	2777.03
6-2300	303.963846	125604	2710.043
6-2400	332.226435	121796	2629.612
7-100	315.110733	119916	2625.387
7-200	410.646619	119150	2521.256
7-300	417.298495	119232	2481.25
7-400	272.783955	120086	2345.867
7-500	466.761531	122303	2075.491
7-600	484.898537	126870	1862.989
7-700	1032.313356	133559	1878.68
7-800	1754.775742	137949	1922.591

7-900	1840.752045	137461	2048.844
7-1000	1783.45792	136548	1759.742
7-1100	1762.912918	135596	1502.892
7-1200	1424.251575	134341	1494.989
7-1300	384.181127	132572	1500.654
7-1400	480.017517	130553	1379.455
7-1500	297.150611	128777	1326.472
7-1600	218.283802	128034	1361.548
7-1700	270.904615	130389	1395.476
7-1800	963.890124	137549	1389.34
7-1900	386.495243	140468	1515.668
7-2000	363.224864	140085	1715.289
7-2100	295.834934	137985	1859.141
7-2200	212.135587	133790	1961.36
7-2300	187.859748	127318	1775.06
7-2400	194.780703	121482	1563.296

PJM Map

PJM operates the power system and electricity market for all or part of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and the District of Columbia. This report relies on data from PJM, so the results of this analysis apply to this area.[23]



[23] http://www.pjm.com/documents/maps.aspx