Negative Electricity Prices and the Production Tax Credit

Why wind producers can pay us to take their power – and why that is a bad thing

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About the Authors

This study was prepared by members of The NorthBridge Group, Frank Huntowski (Director), Aaron Patterson (Principal), and Michael Schnitzer (Director). The NorthBridge Group is an independent economic and strategic consulting firm serving the electric and natural gas industries, including regulated utilities and companies active in the competitive wholesale and retail markets. NorthBridge has a national practice and long-standing relationships with restructured utilities in Regional Transmission Organization ("RTO") markets, vertically-integrated utilities in non-RTO markets, and other market participants. Before and throughout the restructuring process of the U.S. electricity industry, the authors have assisted clients with wholesale market design, competitive market analysis and strategy, regulated power supply procurement, state regulatory initiatives and strategy, and mergers and acquisitions.

Executive Summary

As a matter of both economics and public policy, no government production tax subsidy should ever be so large that it creates an incentive for a business to actually pay customers to take its product. Yet, the federal Production Tax Credit ("PTC") for wind generation is doing just that with increasing frequency in electricity markets across the United States. In some "wind-rich" regions of the country, wind producers are paying grid operators to take their generation during periods of surplus supply. But wind producers more than make up the cost of the "negative price" payment, because they receive a $22/MWH federal production tax credit for every MWH generated.

The federal wind Production Tax Credit ("PTC") was originally enacted in 1992 to jumpstart the wind energy industry.[1] The PTC has since been extended on six occasions and is now due to expire on December 31, 2012. Today, policymakers on both sides of the issue are debating the merits of yet another extension of the subsidy on a variety of grounds. This paper focuses on one harmful, but often overlooked, aspect of the PTC - specifically how the PTC interacts with wholesale electricity markets to create the phenomenon of distortionary "negative prices." While the concept of negative prices might at first glance seem to be a money-saver for electricity users, or at best a harmless phenomenon, in fact these negative prices are: (a) funded by taxpayers; (b) distorting wholesale electricity markets; and (c) harming conventional generation and imperiling reliability. As recently as September 6, 2012 the Public Utilities Commission of Texas Chairman Donna Nelson cautioned policymakers against further subsidies noting that the PTC had undermined Texas reliability:

> "Federal incentives for renewable energy… have distorted the competitive wholesale market in ERCOT. Wind has been supported by a federal production tax credit that provides $22 per MWH of energy generated by a wind resource. With this substantial incentive, wind resources can actually bid negative prices into the market and still make a profit. We've seen a number of days with a negative clearing price in the west zone of ERCOT where most of the wind resources are installed….The market distortions caused by renewable energy incentives are one of the primary causes I believe of our current resource adequacy issue… [T]his distortion makes it difficult for other generation types to recover their cost and discourages investment in new generation."[2]

As part of our analysis, we have reviewed energy production and real time pricing information from the Nation's grid operators to understand the production characteristics and bidding behavior of wind producers and to assess their impact on essential conventional electric resources.

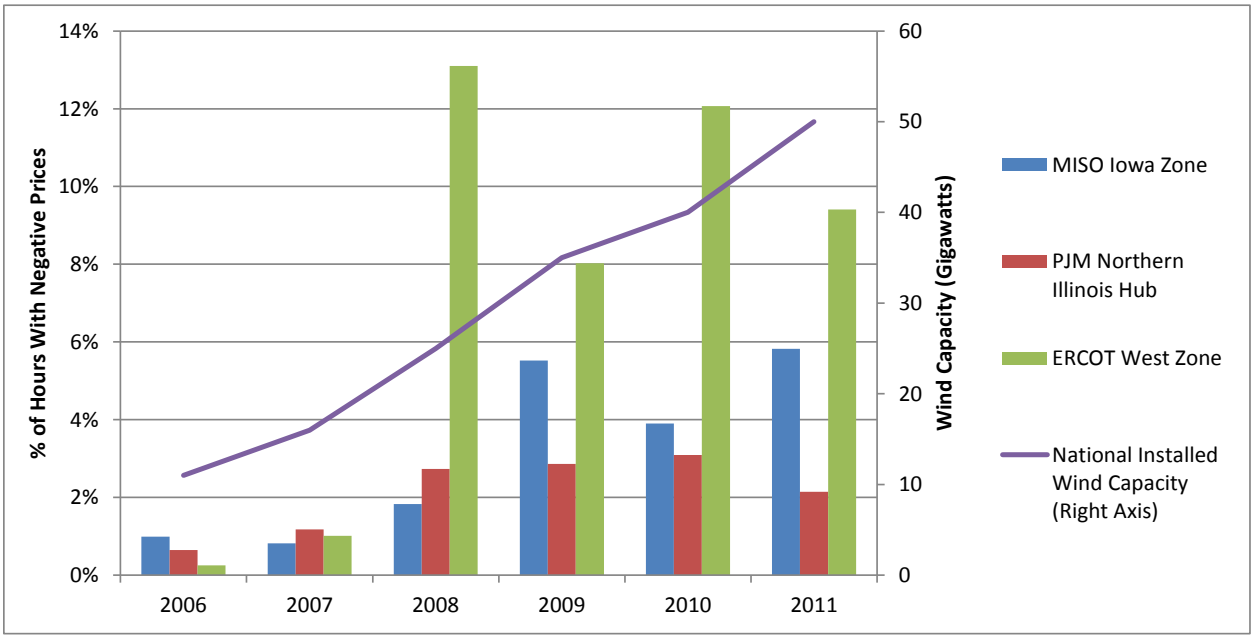
We find that:

- The PTC undermines and distorts price signals in wholesale electricity markets by incenting PTC-subsidized wind producers to sell electricity at a loss to earn enormous tax subsidies.
- This taxpayer-funded subsidy artificially depresses wholesale power prices, and in hours of the year when demand for electricity is low it can result in negative pricing. Figure 1 shows the frequency of negative prices in a number of particularly wind-rich areas over

[1] The PTC increased wind subsidies that originally began in 1978 with the Public Utility Regulatory Policy Act.
[2] Chairman Donna Nelson testimony before the Texas Senate Natural Resources Subcommittee (September 6, 2012), transcribed from http://www.senate.state.tx.us/avarchive/.

2006-11 alongside the growth in national installed wind capacity over the same period. This figure demonstrates the clear linkage between wind generation and negative prices.

Figure 1: Negative Prices are Increasing in Frequency as Wind Generation Expands



Source: Ventyx Velocity Suite; U.S. Energy Information Administration

- Wind producers can readily turn wind turbines on and off, but have no incentive to do so because they still receive positive margins during negative price hours due to the PTC subsidy they earn when they generate. They have no incentive to curtail their output – which, absent the PTC, would be in their economic interest. The failure of wind generators to curtail output when wholesale prices approach zero has both short term and long term negative consequences. In the short term, the failure of wind producers to curtail output makes it more difficult for system operators to maintain reliability, and also makes it more costly for them to operate the regional electric grid.

- In the long run, the PTC destabilizes the market for conventional electricity as generators that are not eligible for the PTC are significantly harmed by negative prices, both in terms of near-term daily operational decisions, as well as long-term decisions to build or retire generation.

- America's continued reliance on the PTC subsidy therefore will invariably deter investments in the conventional power generation needed to maintain a reliable electric system. Conventional generation is critical to reliability because wind generation often does not produce energy during times of peak electricity demand, while producing at high levels (and driving negative prices) when demand is low. In recent years, about 85% of total wind capacity has not operated during the peak hours on the highest

demand days of the year, on average. Controllable conventional generation is thus needed to backstop wind and ensure the lights stay on.

Our findings lead us to conclude that the PTC should be allowed to expire under current law. PTC-driven negative prices directly conflict with the performance and operational needs of the electric system and with federal energy policies supporting well-functioning competitive wholesale markets. We urge policymakers to: (1) reconsider a national energy policy based on a tax incentive so large it incents wind producers to pay system operators to take their wind power; (2) address the reality that wind energy, while an important part of the energy mix, remains unpredictable and cannot be relied upon, especially during periods of high demand; and (3) ensure policies promoting wind do not undermine the conventional technologies that are needed to maintain reliability.

Subsidy-Driven Negative Electricity Prices are Harmful to Competitive Electricity Markets and Consumers

The Energy Policy Act of 1992[3] laid the foundation for competitive wholesale electricity markets. Such markets provide clear, transparent market signals, promote innovation, and enhance efficiency. Market price signals based on supply and demand drive investments in the most economic type of generation resources when and where needed. As a former Chairman of the Federal Energy Regulatory Commission stated, "[C]ompetition does a better job developing and deploying new technologies and…improving operations performance."[4]

As electricity cannot be readily stored, to maintain electric grid reliability system operators must precisely balance supply and demand moment to moment, around the clock. Hourly wholesale electricity prices in competitive markets are driven by the price at which supply (generation) is offered to the market, and how much electric demand there is in each hour. These prices help maintain the required balance. When demand increases, prices rise, signaling generators to produce more power. With low demand, prices fall signaling generators to reduce output to avoid overloading the electric grid. Typically, wholesale prices rise when demand is higher, and fall when demand is lower. Absent wind generation, there are limited circumstances when a grid operator may rely on negative prices to deal with a sudden oversupply of energy (such as a sudden loss of demand) to send appropriate market signals to reduce production. But negative prices driven by the Federal PTC subsidy, which effectively pays wind generators $22 for each Megawatt-Hour (MWh), regardless of whether their power is needed, are not driven by such underlying physical or operational constraints. In fact, wind power production can be readily curtailed when demand is low and it is not needed. But the PTC perversely incents wind operators to continue producing, even when they have to pay the system to take their unneeded and uneconomic power. Such wind-driven negative prices are fundamentally incompatible with, and undermine, economic efficiency and the principals of competitive markets endorsed in the Energy Policy Act of 1992.

Figure 2 shows the hourly price pattern of prices and wind output (depicted as the contribution of hourly wind output to meeting total hourly demand) for a fairly typical day in wind-rich Iowa in the Midwest Independent System Operator (MISO) market in Spring of 2012. In 19 of the 24 hours, wholesale prices are positive. However, in five early-morning hours when electricity demand is lowest but wind production is highest, prices are negative. But because wind developers make so much money from the taxpayer-funded Federal PTC, they ignore the system's signal to produce less electricity.

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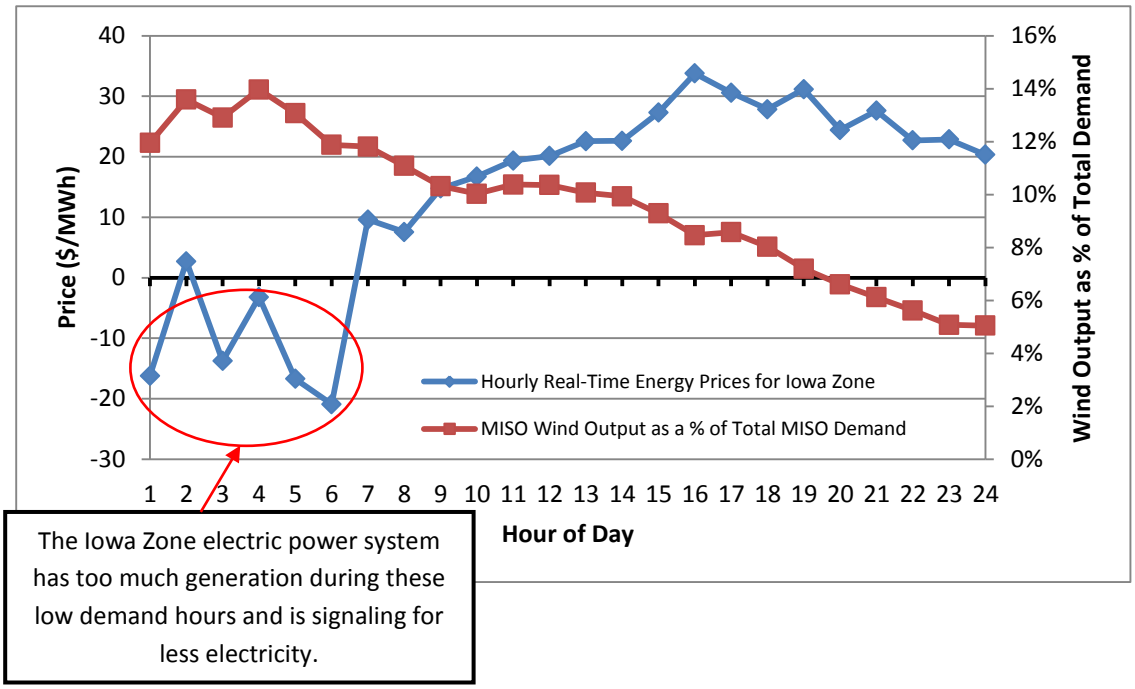
[3] The Energy Policy Act of 1992 created a framework for a competitive wholesale electricity generation market and mandated that the Federal Energy Regulatory Commission ("FERC") open up the national electricity transmission system to wholesale suppliers.

[4] Statement of FERC Chairman Joseph T. Kelliher on Cost of Electric Generation Staff Presentation, June 19, 2008. *See* http://www.ferc.gov/media/statements-speeches/kelliher/2008/06-19-08-kelliher-A-3.pdf.

Figure 2: Real-Time Hourly Electric Energy Prices and Wind Output in the Iowa Zone of MISO on June 14 2012



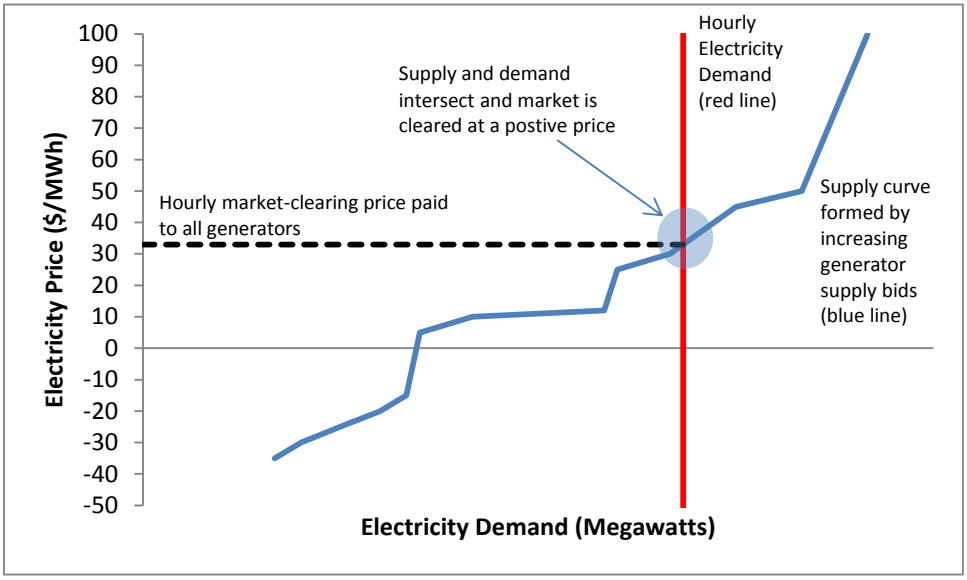
Source: Ventyx Velocity Suite

Being paid to receive a valuable product may sound like a consumer benefit, but PTC-driven negative prices distort vital competitive market incentives, drive up costs, and harm and deter investment in more reliable, conventional generation, including natural gas, coal, hydro and nuclear, that are needed when wind producers do not perform. These price distortions make it more difficult to maintain reliability of the regional electric system and raise costs for society as a whole. The following sections document the increasing prevalence of wind-driven negative prices in certain areas of the country, examine the root causes underlying negative prices, and discuss the problems that result for competitive electricity markets and consumers.

How Wind Tax Subsidies Contribute to Negative Prices

Unlike most products, electricity is not easily stored, and therefore electric system operators must instantaneously match supply and demand to maintain reliability. Most system operators in the United States use market-based signals to manage supply and demand. For instance, regional transmission operators such as MISO or the Electric Reliability Council of Texas (ERCOT), receive supply bids from electric generators on their system (typically reflecting the respective generator's incremental, or marginal, cost of supply--e.g., a generator's fuel cost); they stack those bids in increasing order and then match supply to demand each hour (taking into account operating limits of their transmission system) with the highest-cost generator needed in that hour setting the price charged to consumers and paid to all "cleared" generators. Figure 3 provides a visual illustration of how, under normal operating conditions, the hourly clearing of supply against demand produces positive prices that reflect the marginal cost of supply in that hour.

Figure 3: Hourly Electricity Market under Normal Operating Conditions with a Positive Price



At times, however, low demand combined with generator operating constraints produce a negative hourly price. Why does this happen? Some electric generators cannot vary their output from hour to hour, so rather than submit a positive supply bid, they merely specify to the market operator that they must be kept online at a particular level, regardless of price. As a rule, nuclear units, for example, are scheduled in this "must-run" fashion because normally they operate at a set level of output, regardless of market price, due to low marginal fuel cost, equipment limitations and stringent safety guidelines for operation. Many fossil units are flexible within a range of output, but cannot be cycled down below a certain minimum level without shutting the unit off completely, creating an operationally inflexible minimum block of output. In an hour when a system operator has more "must-run" or zero-bid supply than it has demand, it will post a negative price, to give generators a strong economic signal to curtail generation.

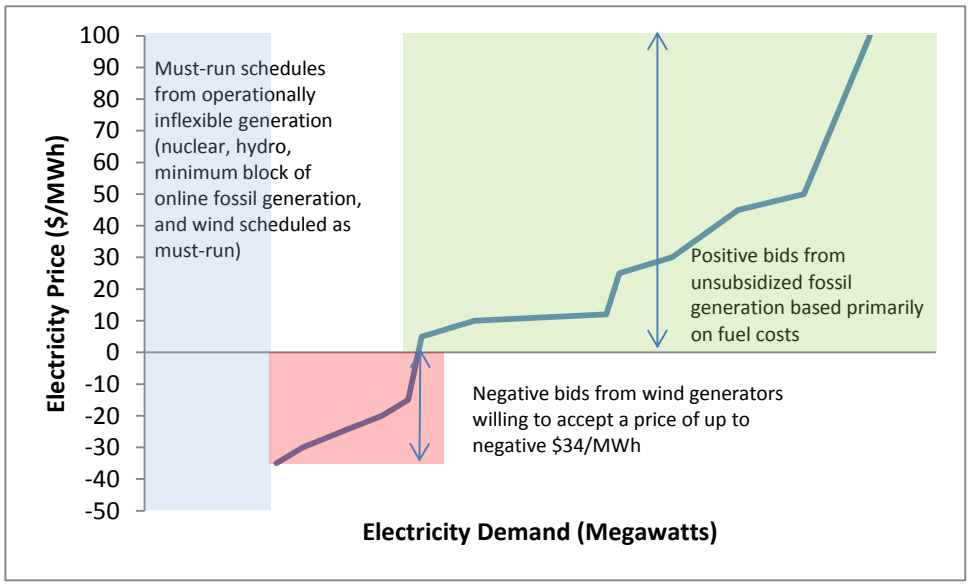
Unlike nuclear and fossil-fueled generation wind generation is physically flexible, as it can be shut down or turned back on reasonably quickly by altering the pitch of the turbine blades or by disconnecting or reconnecting the turbines to the electric grid. Nonetheless, because wind generators receive the Production Tax Credit ("PTC") of $22 per MWh if they generate power in any given hour, they are willing to accept a substantial negative price for their generation, as long as the production subsidy exceeds the negative price. A wind generator still profits as long as a negative market price does not exceed the pre-tax value of the PTC.[5] This means that a wind producer can simply schedule its generation as must-run, regardless of price or it can submit a negative bid of about $34/MWh (-$34/MWh Market Price + $34/MWh Pre-Tax PTC = Margin of Zero). Because all generators whose bids are accepted in a given hour are paid the same market clearing price set by the highest accepted bid, wind producers will typically receive a much higher price than their bid, even if they bid negative prices

[5] Because it is a tax credit, the PTC is denominated in after-tax dollars. Thus the $22/MWh after-tax PTC is equivalent to a pre-tax value of $22 divided by one minus the tax rate, or roughly $34/MWh.

in all hours. If a wind producer receives additional state-funded production subsidies due to renewable portfolio standard payments[6] they can bid a price even lower than negative $34.

In stark contrast, a typical fossil generator incurs fuel costs but receives no production subsidies when it generates (for example, a positive $40 Market Price less $40 Fuel Cost = Margin of Zero). Because a fossil generator loses money if the market price is below its fuel cost, it typically submits a positive bid equal to its fuel costs. While most of the output of a fossil generator will be bid at a positive price, a portion will typically be scheduled as must-run because the fossil generator lacks the flexibility to turn down below a minimum level, despite still incurring fuel costs on this minimum block of output. As a result, as Figure 4 illustrates, in a wind rich region these different bidding practices form a supply curve with several different component parts. A portion of the supply curve will have negative bid prices resulting from the ability of wind producers to submit negative bids due to federal subsidies, another portion will basically reflect zero marginal cost, due to must-run or operationally inflexible generation, and a final portion will have positive bid prices based primarily on fuel costs.

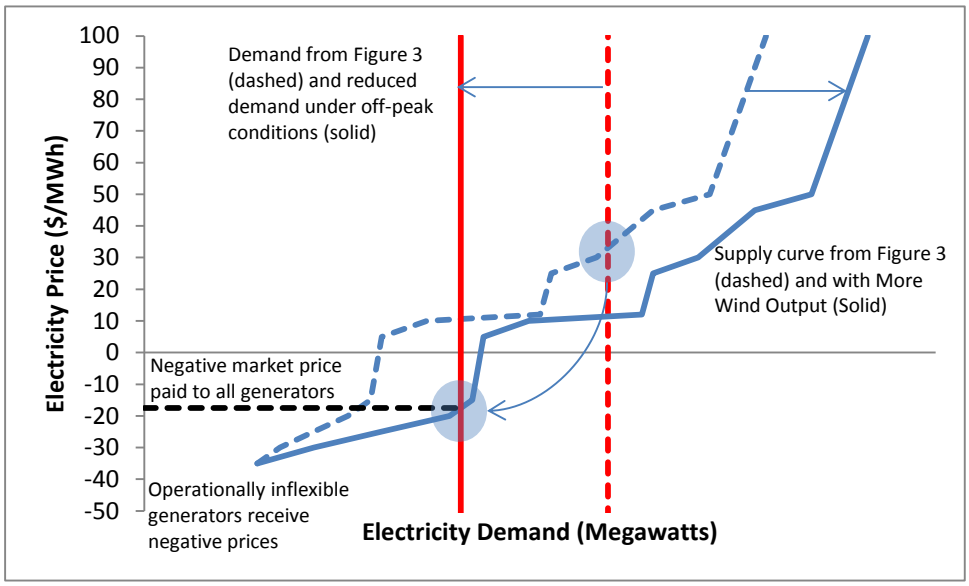
Figure 4: Generation Supply Curve in Wind-Rich Region



Under certain system conditions (e.g., low demand hours with high wind generation and limited available transmission capacity to transmit the excess wind generation to other regions) negative bids can actually set the clearing price for a region. Figure 5 shows how these various factors - PTC-driven negative price bids from wind generation, low demand in certain hours, and operationally inflexible generation - can all combine to produce negative prices. When demand is low and the share of operationally inflexible baseload generation and negatively-bid wind is high, the negative-priced portion of the supply curve actually clears the market.

[6] In thirty states plus the District of Columbia, wind generators also receive state-funded production subsidies.

Figure 5: Combination of Low Demand and High Wind Output Produces Negative Prices



Negative prices in themselves are not inherently bad. If they reflect real time underlying physical and economic constraints (i.e., low demand and operational inflexibility) they send the right market signals. But, if they are subsidy-driven and unrelated to real time operational and economic constraints, they distort the market by sending incorrect price signals which harm the reliable and cost effective operation of the electric system.

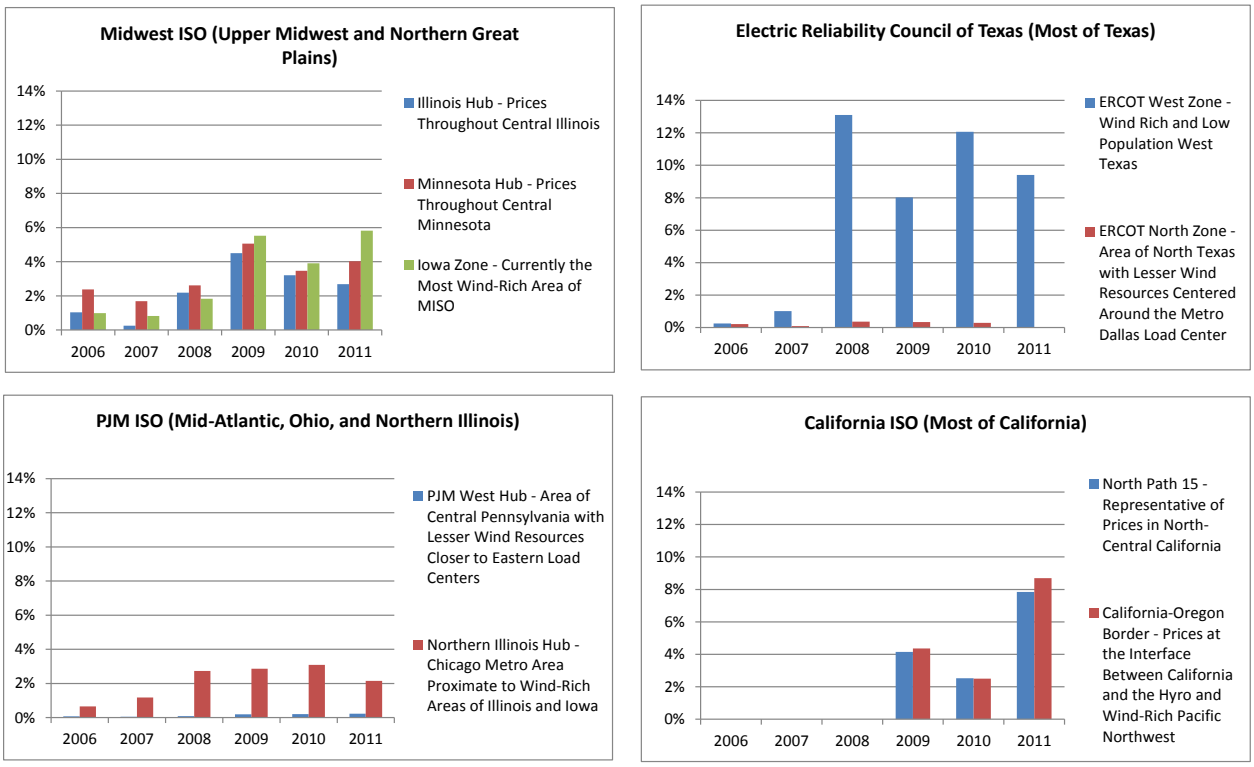
Unfortunately, wind producers' negative bids fall into this latter category. They are a distortion caused by the production-based nature of wind subsidies rather than any reflection of real underlying physical or economic constraints associated with wind production. There are no real economic costs associated with curtailing wind generation that would justify a negative price. Given the capability of wind generators to readily reduce output in the absence of the "use it or lose it" PTC, wind producers would have an incentive to stop generating at a zero price. Instead, wind producers' subsidy-driven negative bids essentially reveal their ability to shift costs to others to continue to earn the production tax subsidy, even when the most economically efficient outcome would be to shut down their production when the market price reaches zero.

Wind-Driven Negative Price Events are Increasing in Frequency

Actual data from electricity markets clearly demonstrates that in recent years wind generation is the primary catalyst for the increasing prevalence of negative electricity prices, which account for up to 13% of all hourly prices in some regions. To illustrate the problem, Figure 6 shows the percentage of hours with negative prices from 2006 to 2011 in four major U.S. organized electricity markets, which collectively serve over 150 million customers. During this period, significant new wind generation has been developed in MISO (covering much of the upper Midwest and Northern Great Plains), PJM

Interconnection (covering electricity 13 Midwest and Mid-Atlantic states), ERCOT (covering most of Texas), and the California ISO.[7]

Figure 6: Percentage of Hours with Negative Real-Time Electric Energy Prices in Wind-Rich Electricity Markets, 2006-11

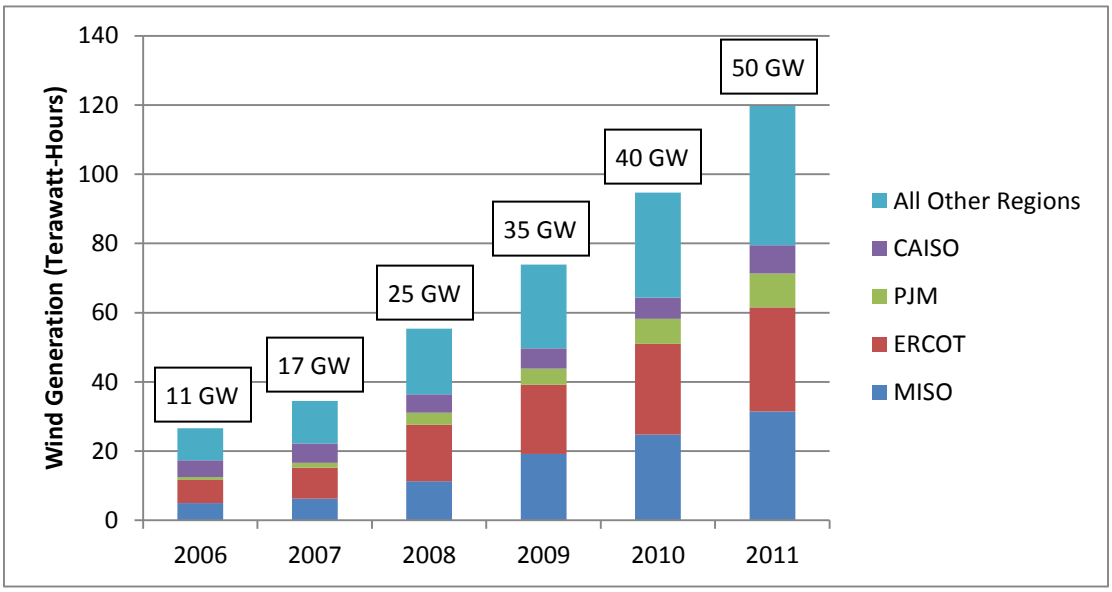


Source: Ventyx Velocity Suite; California ISO data not available prior to 2009

As shown in Figure 6, in each market, hours with negative prices have increased from very low incidence in 2006 and 2007 to much higher levels from 2008 to 2011, and largely have been located within the wind-rich areas of each market such as the ERCOT West Zone, the Northern Illinois Hub in PJM, the Iowa Zone in MISO and CAL ISO. The parts of each market closer to demand centers and further away from the wind-rich areas have been less affected, such as the PJM West Hub in Pennsylvania, and the ERCOT North Region centered around the Dallas metropolitan area. Figure 7 shows that nationally wind generation has increased nearly five-fold from 2006 to 2011, clearly paralleling the increase in negative price events over that time.

[7] While negative prices are frequent and visible in these four markets, they are increasing in frequency in a number of other regions of the country with less organized visible markets as well. In particular the Western Electric Coordinating Council (covering most of the country from the Rockies to the Pacific) and the Southwest Power Pool (covering much of the lower Great Plains and Midwest) also experience significant operational issues caused by negative prices and wind-subsidy-related distortions.

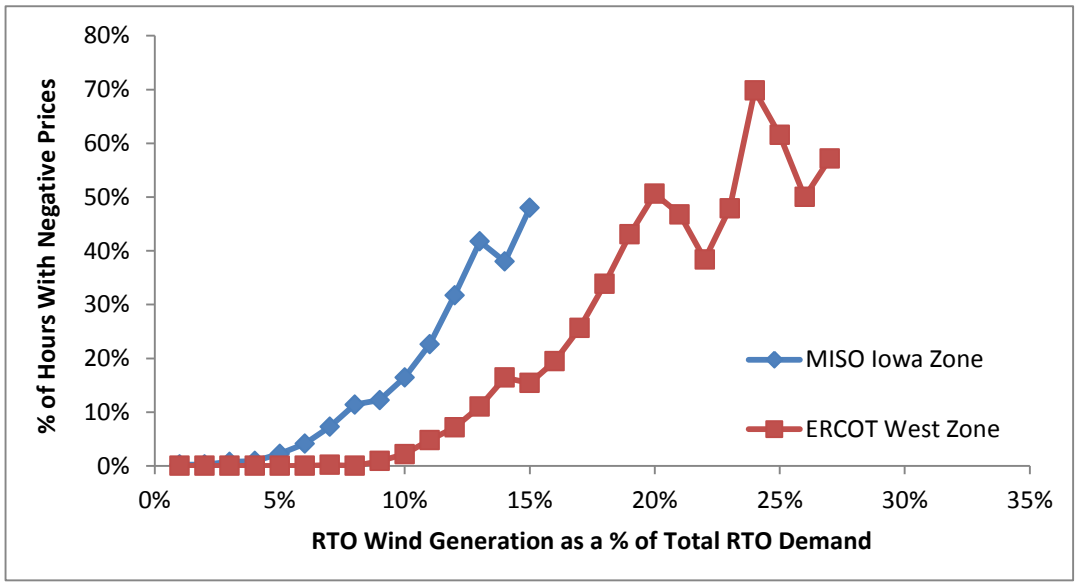
Figure 7: Total U.S. Wind Generation Output, 2006-2011



Source: U.S. Energy Information Administration; Market classification is approximated from state-level data

A closer examination of the data for each market confirms that negative prices tend to occur in times of low demand and high wind output. Figure 8 plots the output of wind generation relative to total demand on an hourly basis versus the prevalence of negative prices in wind-rich regions across MISO and ERCOT. Thus, for hours in which wind generation output is small relative to total demand (i.e., less than 5%, indicating that demand is high and/or wind output is low), Figure 8 indicates that negative prices account for less than 2% of the hourly prices in such hours. However, for hours in which wind generation forms a relatively high proportion of total demand (i.e., greater than 10% in MISO or greater than 15% in ERCOT, indicating low demand / high wind system conditions), we find that the frequency of negative prices greatly increases, reaching 50% or higher in hours in which wind is most prevalent.

Figure 8: Prevalence of Negative Price Hours versus Wind Generation in 2011



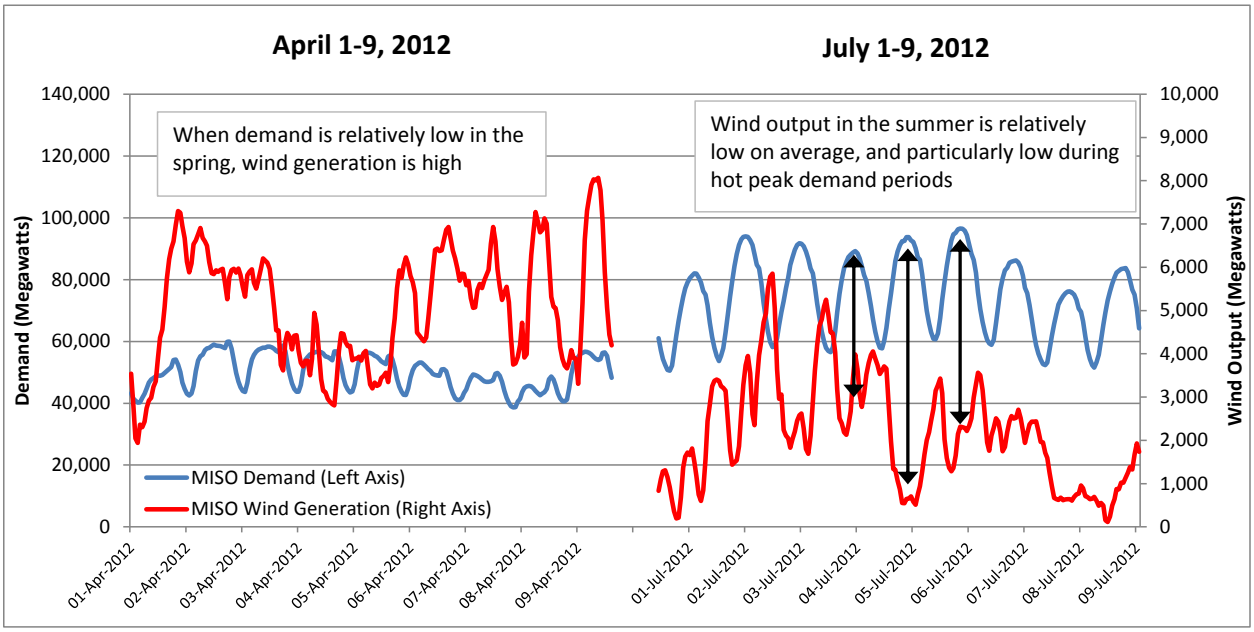
Source: Ventyx Velocty Suite

Figure 8 further confirms the linkage between negative prices and wind generation: as wind output increases and demand decreases, the frequency of negative prices increases dramatically. Overwhelmingly, negative prices are most prevalent when wind output is highest relative to overall demand, such as during the overnight hours in the spring and fall months when wind output is high but demand is relatively low and less power is needed. By contrast, negative prices do not occur when the wind is not blowing but demand is high, such as during summer peak hours.

Wind Often Does Not Perform When Demand Is Greatest

The fact that wind generation disproportionally influences prices in periods of low demand for power is a result of wind generation's intermittent nature and unfavorable output pattern. To maintain reliability, electric system operators need generation resources to be available when electricity demand peaks and they need the most power to supply the system. Yet on both an hourly and seasonal basis, data from the system operators confirms that wind output is consistently lowest when demand is greatest, such as on hot humid summer days, and highest in Fall and Spring when electric demand is the lowest. Figure 9 utilizes actual hourly demand and wind output in MISO earlier in 2012 to illustrate this problem. On the left hand side of Figure 9 we plot the total hourly demand in MISO for the first nine days of April 2012 together with the MISO-wide wind output for the same period. On the right hand side we plot the same data for the first nine days of July 2012.

Figure 9: Wind Output and Electric Demand in the Spring and Summer in MISO

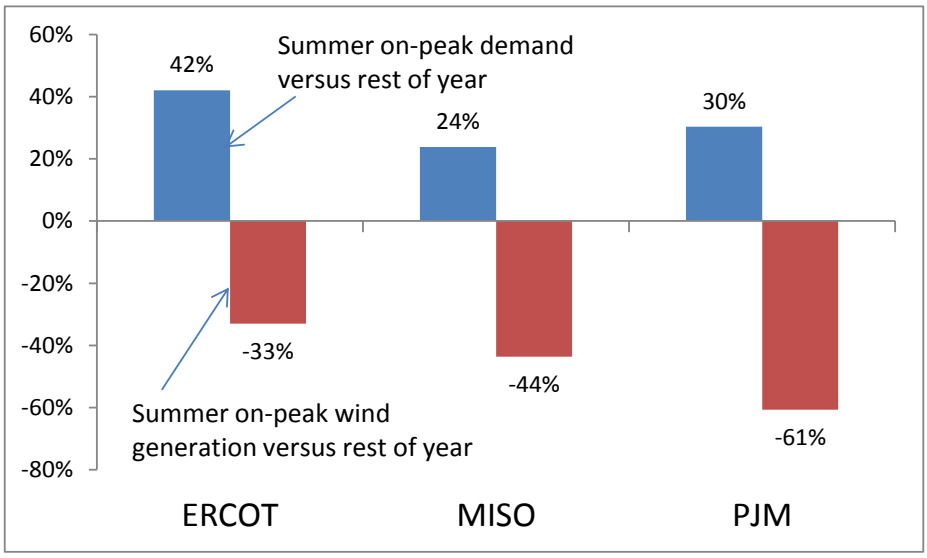


Source: Ventyx Velocity Suite

The difficulties that wind's unfavorable production pattern creates for reliable system operation is further exacerbated by the typical daily patterns of wind production during summer months. For instance, we see that the daily production profile of wind in July is inversely correlated with demand; when demand is highest (during hot summer days) wind output is at its lowest and during the nighttime when demand is relatively low wind generation is at its highest. Furthermore, compared to wind production in April, production in July is much lower on average. This unfavorable wind production shape is not under the control of system operators; rather, it is purely a function of fluctuating wind patterns. Accordingly, controllable (or "dispatchable") generation is required to substitute for wind generation if the wind does not blow during peak demand conditions. This phenomenon of wind generation not correlating with peak load conditions occurs consistently in all markets with significant wind generation.

Figure 10 shows the "wind gap" between demand and wind output during summer on-peak hours (the sixteen hours during each weekday roughly corresponding to daylight hours). Demand and wind output for the summer on-peak period are shown relative to their average level across all hours of the year. Throughout 2011 in MISO, PJM, and ERCOT summer on-peak demand ranged from 24% to 42% *higher* than average demand during the year, while wind output was between 33% and 61% *lower* than its average during the year.

Figure 10: "Wind Gap" when Demand Peaks in the Summer

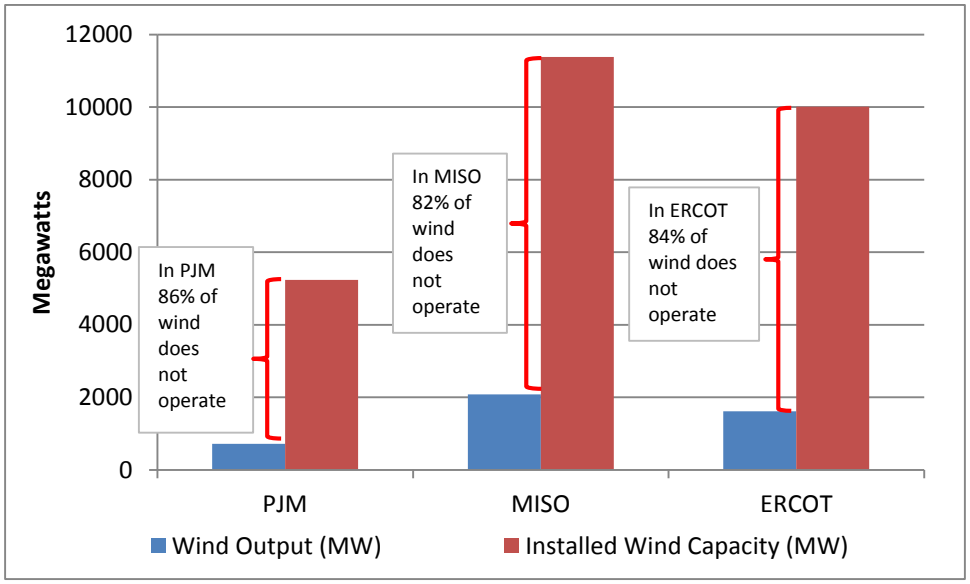


Source: Ventyx Velocity Suite

During the most critical peak demand hours of the year from a reliability perspective (defined as the peak demand period of each of the 10 highest demand days in each year) most wind capacity does not deliver needed energy to the system. As shown in Figure 11, between 82 and 86% of designed wind capacity was not operating during the top 10 peak demand days in PJM, MISO, and ERCOT in 2012.[8] In contrast, only about 10% or less of conventional generation capacity will typically be unavailable during these periods.

[8] Over the longer period from 2009 to 2012 this analysis yields similar results. Over this four-year period, median unavailability of wind capacity in the on-peak period of the top 10 demand days of the year was 87%, 87%, and 82% in PJM, MISO, and ERCOT, respectively.

Figure 11: Median Wind Output Relative to Capacity during On-Peak Hours of the Top 10 Demand Days of 2012



Source: Ventyx Velocity Suite

The Federal PTC thus costs taxpayers billions of dollars for a generating resource that produces the least amount of electricity when it is needed the most. And, as explained below, the negative prices created by the PTC penalize other resources that are critical to backstopping wind's fluctuating output.

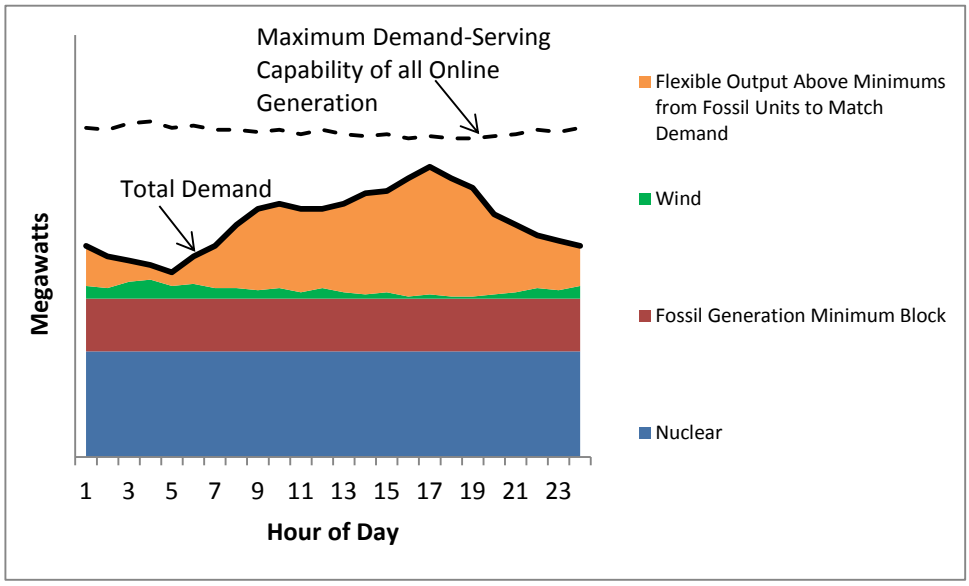
The Harmful Impacts of Negative Prices: Increased Costs and Reliability Risks

Wind-driven negative prices have both short and long term harmful effects. In the short term, they disrupt the operation of physical electricity systems and markets by sending distorted hourly price signals to other market participants whose resources are needed to meet demand reliably and cost-effectively. Unit commitment decisions for fossil generation illustrate this adverse impact. Most fossil generation, such as natural gas combined-cycle gas turbines, cannot be turned completely on or off on an hourly basis. Rather such units typically require several hours of notice to be turned on or "committed", and once on typically must remain on for between four and 24 hours. And if turned off or "decommitted" they must remain offline for several hours.

Once committed, a typical fossil unit must operate at a minimum level. For example, a coal unit with a 500 Megawatt ("MW") capacity may be able to quickly vary its output between 100 MW and 500 MW, but cannot remain online but decrease output below the 100 MW level. Under normal operating conditions, because offline units cannot always be committed quickly enough to meet rapidly increasing demand, an electricity market operator will keep a number of fossil units operating at minimum levels during low demand hours so as to reliably meet demand later in the day as demand increases but wind does not blow. While such units have inflexible aspects (such as their inability to be fully turned on and off in real time), their ability to precisely and quickly follow load in real time is a key component of the system's overall flexibility in responding to fluctuations in supply and demand to maintain reliability. In contrast, wind generation output is unpredictable and cannot be ramped up to meet increasing demand, and in fact usually falls off during peak demand periods. The only thing controllable about

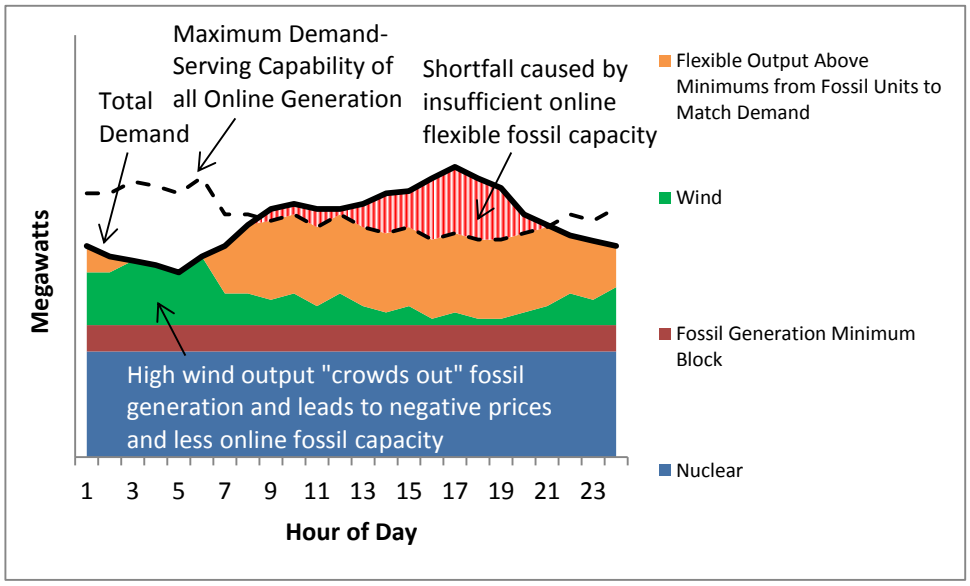
wind is the ability to decrease or shut off output when the wind is blowing. Figure 12 shows how each resource normally works across a typical operating day.

Figure 12: Electric Generation Serving Demand under Normal, Positive-Price Conditions



Negative prices driven by tax subsidies for wind distort competitive markets, disrupt normal operation of the system, raise costs, and imperil reliability. In particular, subsidized wind economically undermines essential fossil generation operating at minimum levels during low demand periods. Negative prices make operating fossil generation at minimum levels extremely expensive as operators must pay not only for their fuel costs, but also just to generate. Figure 13 illustrates this harmful impact.

Figure 13: Generation Shortfall Caused by Wind-Driven Negative Prices



These disruptions caused by wind-driven negative prices create significant difficulties for the system operator. Faced with requests to decommit fossil thermal units which are critical for reliability, the operator must either resort to uneconomic command and control measures to ensure that sufficient reserves are available (with the costs charged to all electric users) or operate the system less reliably. Generally, electric system operators err on the side of preserving reliability at the expense of cost-effectiveness and favor out-of-market solutions which preserve their ability to operate the system reliably, but impose substantial costs on consumers. Examples of such costly, inefficient reliability solutions include carrying and paying for more operating reserves, paying revenue sufficiency guarantees which effectively pay generators to commit their units regardless of price signals, and manually backing down non-wind operationally inflexible generation such as hydro under off-peak excess generation conditions.[9] Because of wind generation's unpredictable fluctuations, the system operator must pay the fossil generators to remain available even when it is highly uneconomic for them to do so. As such these wind-driven reliability measures are much more costly for consumers than normal economic operation of the system. Furthermore, forcing fossil generators to start and shut down much more frequently because of wind-driven negative prices increases wear and tear on the units, reducing their reliability and economic life.[10]

[9] The reliability difficulties and economic costs created by negative prices and wind intermittency are well recognized by system operators. The Bonneville Power Administration in the Pacific Northwest, for example, has been struggling to manage over-generation from wind that forces it to wastefully spill hydro resources that are an important source of controllable generation in the West during peak conditions. MISO has recently implemented a "Dispatchable Intermittent Resource" protocol that strongly encourages wind resource to provide dispatchable bids rather than simply schedule their generation as must-run which moderates (but does not eliminate) negative prices and increases flexibility during high-wind operating conditions. In both cases wind generators have objected to these measures, likely due to concerns about losing a portion of the PTC benefits.

[10] Further, contrary to some assertions, building costly additional transmission in wind areas offers no viable solution. Rather, it merely re-categorizes and reallocates the increased costs, but does not eliminate or even significantly reduce them. In the first place, these tremendous additional transmission costs are incurred only

In the longer-term, wind-driven negative prices distort the price signals developers and investors rely on to determine what, when and where to build generation and transmission. Negative prices lower the expected future revenues for all types of base load and intermediate generation that does not receive production-based subsidies.[11] Conventional base load power plants, such as nuclear, hydro, coal, and natural gas combined-cycles, are most affected by wind-driven negative prices. As discussed earlier, unlike wind, this conventional capacity is controllable and reliable, and essential to meet demand throughout the year, particularly in summer peak periods. Wind-driven negative prices, however, severely challenge the economics of these units, increasing the likelihood existing units will choose to retire, and deterring build of new capacity. The cumulative adverse impacts are real and substantial. Over time, these distorted build/retirement decisions can significantly jeopardize the overall ability of the electric system to operate reliably without increased reliance on higher prices in capacity markets, which are already controversial. This increase in capacity prices would be uneconomic and unnecessary but for the subsidy-driven negative prices.

Moreover, effectively paying customers to consume electricity through negative prices driven by taxpayer-funded subsidies cannot be good public policy. It sends a distorted price signal that causes customers to consume more power during negative price periods than they otherwise would. It undermines conservation. Sustained negative prices can cause wasteful investments by sophisticated industrial consumers, who follow hourly price fluctuations. For example, taken to its extreme, negative prices could incent developers to build high electricity consuming elements to use negative-price hours in wind-rich regions, for the sole purpose of being paid to waste electricity.

Another secondary but important effect is that, negative prices in wind-rich regions can create an incentive to overbuild transmission between wind-rich areas and load centers, which will ultimately harm customers because once built, transmission costs are ultimately passed through to consumers regardless of economic value. The economic signal to build transmission reflects the expected difference in prices between two regions. If the price in a wind rich region is depressed due to taxpayer funded PTCs, then a decision to build transmission to ship power out of the region is essentially a decision to build enough transmission such that wind generators can maximize their PTC benefits and other subsidies. Consumers would ultimately bear the costs of any such excessive transmission buildout.

Conclusion

Based on the evidence presented in this paper, it is apparent that the distortionary incentives and bidding practices caused by production-based wind subsidies, in particular the PTC, have caused high prevalence of negative prices in recent years. These PTC-distorted price signals create a range of near- and long-term problems for electricity markets. The PTC subsidy for wind generation artificially dilutes the incentives for conventional generation – generation that is critical for maintaining reliability. While the PTC was originally intended twenty years ago to jump-start a nascent wind industry, the wind industry today is a full-scale global industry and the PTC's primary effect in the current environment is to distort and disrupt incentives for the electricity industry as a whole.

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because of underlying operational problems caused by wind. Moreover, additional costly transmission cannot change the underlying fundamentals causing distortionary wind-driven negative prices.

[11] While negative prices arise in hourly real-time and day-ahead energy markets they also impact longer-term forward markets that investors use to estimate expected future revenues and thus evaluate and price electricity assets.

Our findings lead us to conclude that the PTC should be allowed to expire under current law. PTC-driven negative prices directly conflict with the performance and operational needs of the electric system and with federal energy policies supporting well-functioning competitive wholesale markets. We urge policymakers to: (1) reconsider a national energy policy based on a tax incentive so large it provides wind producers with an incentive to pay system operators to take their wind power; (2) address the reality that wind energy, while an important part of the energy mix, remains unpredictable and cannot be relied upon, especially during periods of high demand ; and (3) ensure policies promoting wind do not undermine the conventional technologies that are needed to maintain reliability.