# Renewable Energy Builds a More Reliable and Resilient Electricity Mix

**American Wind Energy Association** I www.awea.org

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# Executive Summary

**Some of the most common questions about renewable energy focus on how wind and solar can be reliably integrated into the power system.** Many people are unaware of technological advances that allow wind and solar to provide grid reliability services as well as or better than conventional power plants. The following report answers 14 of the most frequently asked questions with lessons learned from grid operators' experiences reliably integrating large amounts of renewable energy. Concise answers to these questions are provided here in the executive summary, while citations and explanations of the supporting data and analysis for those answers can be found by using the following hyperlinks to the relevant sections of the full report below.

### 1. How much wind energy are grid operators integrating now?

U.S. wind energy provides enough electricity to power the equivalent of over 25 million homes. Iowa and South Dakota reliably produced more than 30% of their electricity from wind last year, and a total of nine states are above 15%. At times, wind has supplied more than 60% of the electricity on the main utility system in Colorado, and more than 50% of the main Texas power system and the Southwest Power Pool system. These power systems have seen electric reliability increase.

### 2. How much more renewable energy can we reliably integrate?

While U.S. and European grid operators have already reliably integrated large amounts of wind energy, studies indicate that we can go far higher. Studies examining obtaining 50% or more of our electricity from wind and solar have found no major obstacles to doing so. Ten years ago some utilities and grid operators were concerned about reaching 5% wind; the technology advances and lessons learned that have allowed that to be exceeded over the last decade are likely to continue in the future.

### 3. Don't we need baseload?

Instead of using the term "baseload," it is more accurate to talk about the three main services the grid needs to operate reliably: energy, capacity, and flexibility. Energy is the production of electricity, capacity is the ability to produce power during periods of high demand, and flexibility is the ability to change output to keep supply and demand in balance. Cost-effectively obtaining all three services requires a division of labor among a diverse mix of energy sources, as no resource excels at providing all three. For example, coal and nuclear plants typically do not provide significant flexibility, and other resources can provide energy and capacity at lower cost. Wind energy fits well into this mix as a low-cost source of energy, though it also provides some capacity and can provide flexibility when it is economic to do so.

### 4. What happens when the wind doesn't blow?

Other plants provide energy at those times, in the same way that all power plants back up all other power plants. Portfolio diversity is the key, as no resource is available 100% of the time. All power plants have reduced output at times, and grid operators plan for wind's contribution using the same tools they use to evaluate the contributions of other resources. Adding wind power never increases the need for power plant capacity, but rather reduces it. During a number of events wind has demonstrated its contribution to a more diverse and resilient energy portfolio by stepping in when other resources failed unexpectedly.

### 5. Why are coal and nuclear plants facing economic challenges?

Cheap natural gas, not renewable energy, is the primary factor undermining the competitiveness of coal and nuclear plants. Wind and the production tax credit (PTC) are compatible with well-functioning electricity markets. Wind's impact on other generators is market-driven and the same as that of any low-cost generator, and small compared to other factors.

## 6. Can renewables provide the reliability services provided by conventional generation?

Yes. As wind energy has grown to provide a larger share of our electricity mix, renewable energy technology has matured so that modern wind and solar plants are able to provide the same grid reliability services as conventional generators, including voltage and reactive power control, frequency and inertial response, active power control, and voltage and frequency ride-through. In some cases the reliability services provided by renewables exceed those of conventional generators, while in other cases conventional generators can provide those services more economically than wind generators, but wind generators can provide those services if it becomes economic to do so.

## 7. What about the variability of renewable energy?

Variability and uncertainty are nothing new for grid operators, as they have always dealt with large and unexpected fluctuations in electricity supply and demand by changing the output of power plants. Most changes in wind output are canceled out by other offsetting changes in electricity supply and demand, and any remaining variability is accommodated using the same flexible reserves that grid operators have always used. In fact, because changes in wind output occur gradually and can be forecasted, they are less costly for grid operators to accommodate than the abrupt failures of large conventional power plants. Contrary to most people's intuitive experience that winds are variable and electricity demand and supply is stable, the opposite is actually true at the grid operator scale.

## 8. How much does it cost to integrate renewable energy?

Grid operator data show that increasing the use of existing flexible resources to accommodate wind and solar amounts costs only pennies on a typical electric bill. In fact, the cost of accommodating the unexpected failures of large conventional power plants is far higher.

## 9. Don't grid operators need to add backup to integrate wind?

No. One of main reasons why an integrated power system was first built more than 100 years ago was so all power plants could back up all other power plants. Because most sources of variability cancel each other out, having a dedicated backup source for each would be highly inefficient and counterproductive.

## 10. What steps help accommodate higher levels of renewable energy?

Market-based grid operating reforms and transmission upgrades are by far the lowest hanging fruit for making the power system more efficient by using more of the flexibility that already exists on the power system. These grid operating reforms provide major net benefits to consumers and improve reliability even without renewable energy on the power system, so they should be implemented anyway.

## 11. Isn't energy storage necessary to integrate wind?

No, but it can be helpful. Very large amounts of wind energy can be reliably integrated at low cost without a need for energy storage. Energy storage provides a variety of services and is therefore best viewed as a system resource and not a resource for renewable energy. Energy storage is typically a more expensive source of flexibility than grid operating reforms that allow greater use of the flexibility that already exists on the power system.

## 12. Why is some wind power curtailed? How does time of production affect the value of wind energy?

In some areas the growth of wind energy has outpaced the addition of transmission. At times this has required reducing, or curtailing, the output of wind plants until new transmission is added. However, as long-needed grid upgrades are completed, wind curtailment is being virtually eliminated, as are occurrences of negative electricity prices. Wind energy always has high economic value, particularly once the environmental and public health costs of fossil fuel generation are taken into account.

## 13. What has been Europe's experience with renewable energy?

European nations have demonstrated that wind energy can reliably provide a large share of our electricity, with Ireland, Spain, and Portugal obtaining around 20% of their electricity from wind on an annual basis, Germany at 25% from wind and solar, and Denmark at nearly 35% wind. Carbon emissions have fallen drastically in all of these countries, while electric reliability has been maintained at world-leading levels and in many cases improved.

## 14. What is wind's net impact on emissions?

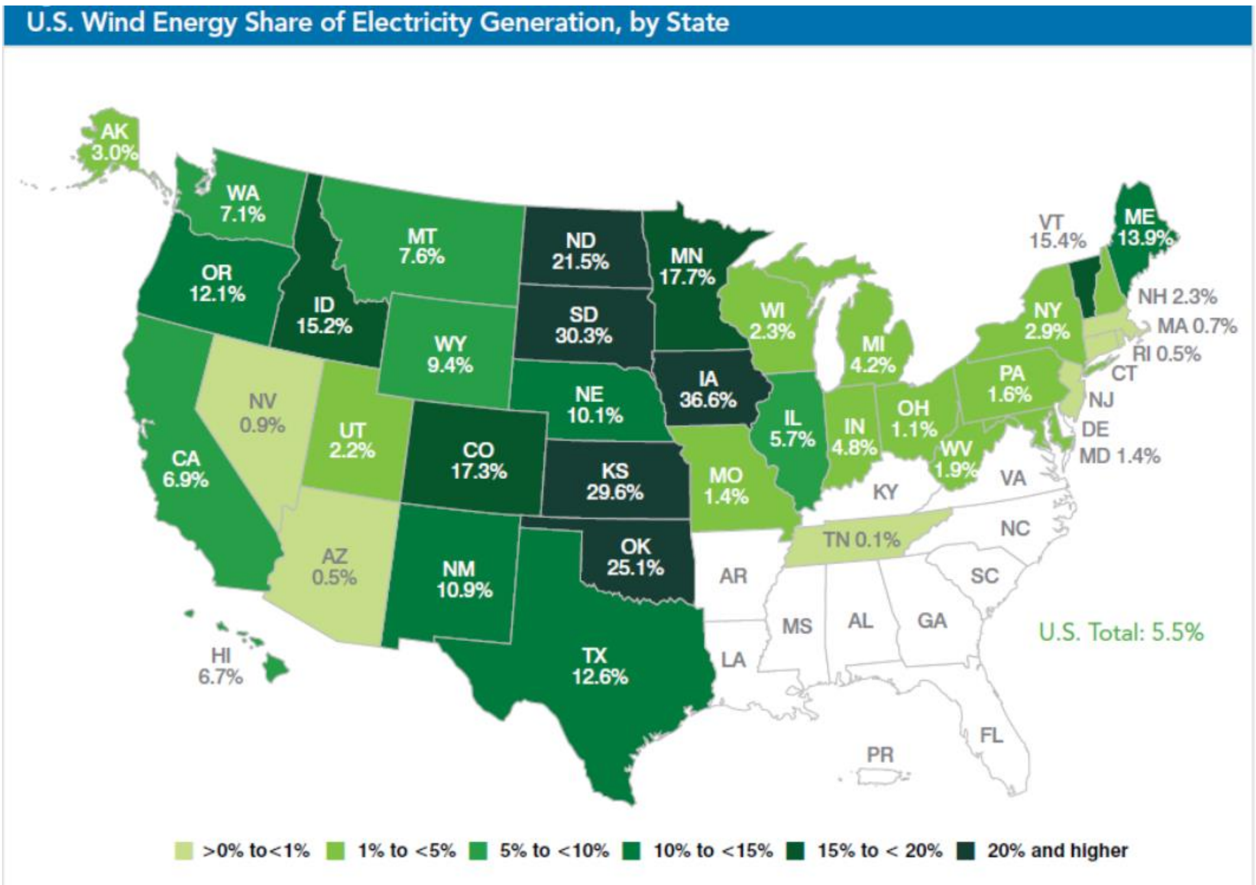
Wind energy greatly reduces emissions of carbon dioxide and other pollutants after all impacts on other power plants are taken into account.

As should be apparent from the extensive evidence provided in the full text below, this report seeks to distill tens of thousands of pages of analysis by grid operators and other experts into a more digestible document. Additional technical support for the points made in this document can be found in a similar 2009 FAQ authored by some of the world's leading renewable integration experts in the journal of the Institute of Electrical and Electronics Engineers (IEEE).[1]

[1]http://www.consultkirby.com/files/Wind_Myths_Debunked_IEEE_2009.pdf

# 1. How much wind energy are grid operators integrating now?

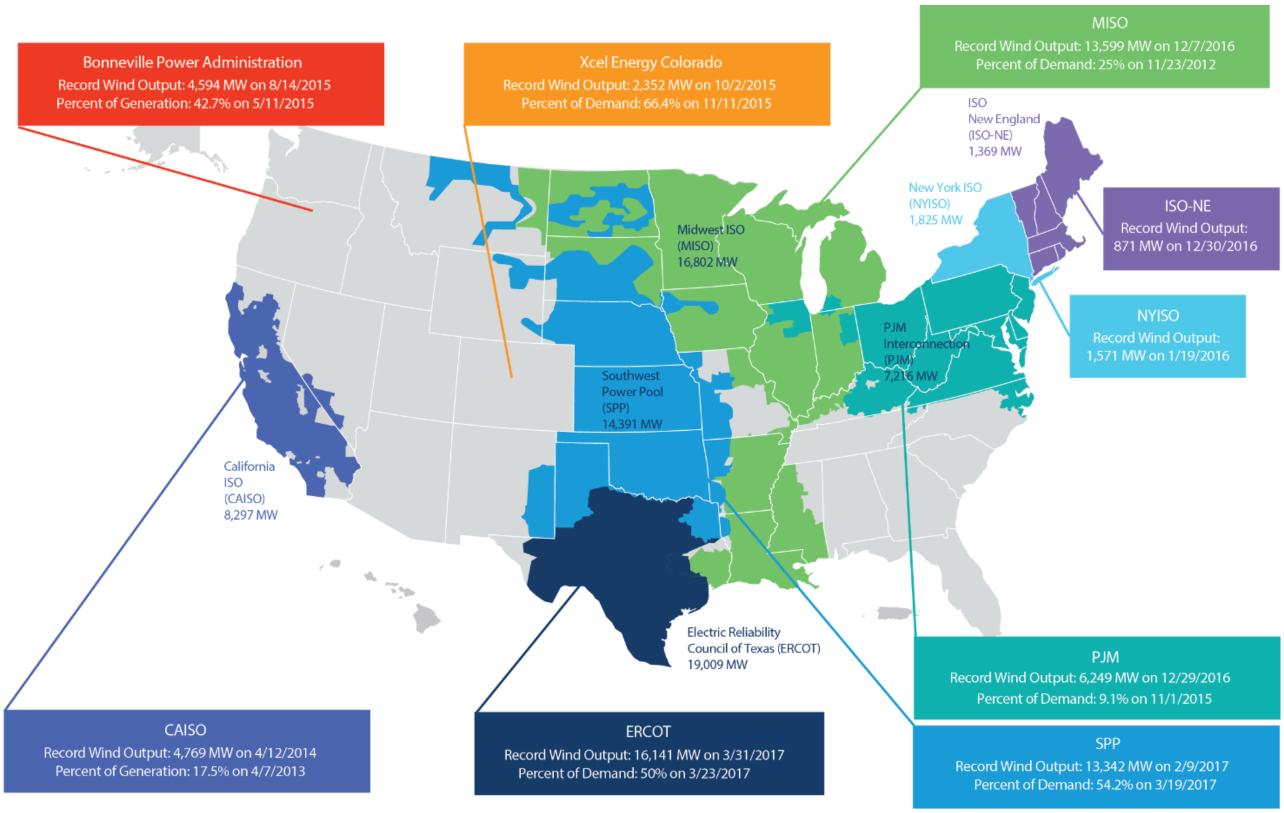
**U.S. wind energy reliably provides enough electricity to power the equivalent of over 25 million homes.** Iowa and South Dakota produced more than 30% of their electricity from wind in 2016, and Kansas and Oklahoma exceeded 25%. The main Texas power system (ERCOT) obtained 15% of its electricity from wind last year, the Southwest Power Pool (SPP) is approaching 20%, and both are reliably adding more.[2] Nationwide, wind is only 5.5% of generation, indicating many regions have significant room to grow.



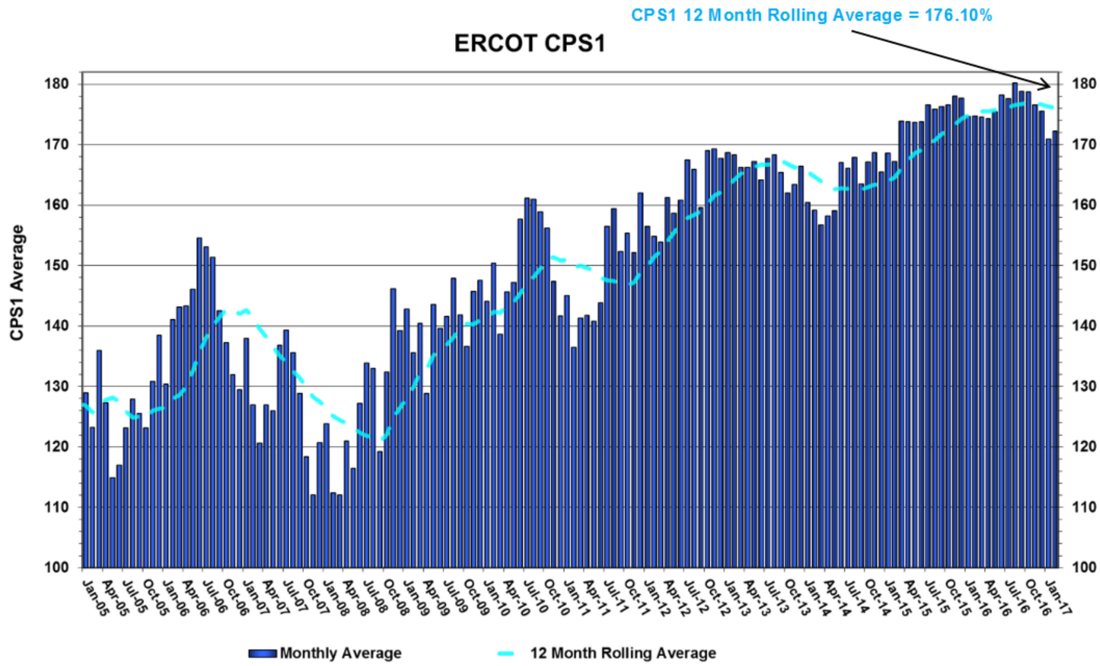

[2] https://www.xcelenergy.com/staticfiles/xe-responsive/Admin/Managed%20Documents%20&%20PDFs/CO-2017-Renewable-Energy-Plan-Fact-Sheet.pdf, http://www.ercot.com/content/wcm/lists/89476/ERCOT2016D_E.xlsx, https://marketplace.spp.org/web/guest/generation-mix-rolling-365

At certain times, wind output levels have gone even higher. The map below shows instantaneous wind generation records and the record percent of demand or generation from wind. At times, wind has supplied around two-thirds of the electricity on the main utility system in Colorado, and over 50% in ERCOT and SPP, all without any reliability problems.

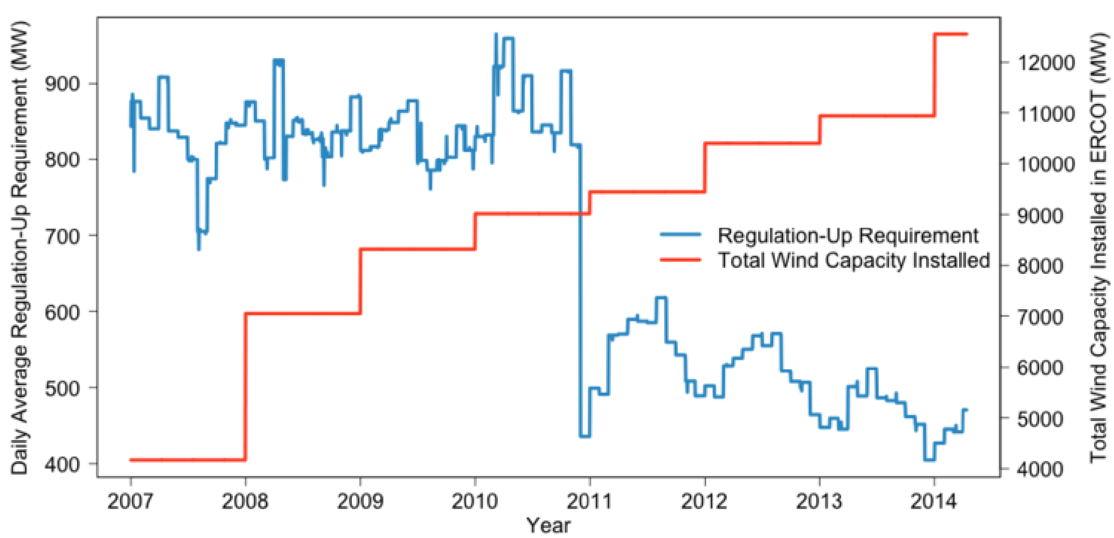
## Wind energy output records by region



These power systems have maintained or improved electric reliability as they have added large amounts of wind energy. For example, ERCOT, which has most wind capacity of any U.S. power system, has seen its electric reliability scores increase dramatically as it has added wind energy. The following chart shows the increase in ERCOT's CPS1 score, which is a widely-used reliability metric that measures how electricity supply and demand are kept in balance. While many factors affect reliability and CPS1 scores, adding large amounts of wind energy clearly has not degraded electric reliability in Texas.[3]




Researchers at the University of Texas at Austin compiled the following chart from ERCOT data, showing that the growth of wind energy has also not caused a significant increase in the need for the frequency regulation reserves that are used to keep electricity supply and demand in balance.[4] Many other U.S. grid operators have found the same result, as discussed in Chapter 8 below.




[3]http://www.ercot.com/content/wcm/key_documents_lists/27311/ERCOT_Monthly_Operational_Overview_201702.pdf
[4]http://theconversation.com/are-solar-and-wind-really-killing-coal-nuclear-and-grid-reliability-76741

# 2. How much more renewable energy can we reliably integrate?

More than a dozen wind integration studies by U.S. grid operators and others have found that wind energy can reliably supply at least 20-30% of our electricity on an annual basis,[5] with some studies analyzing wind providing 40% or more of total electricity. For example, the National Renewable Energy Laboratory's (NREL's) Renewable Energy Futures study found no reliability problems for a case in which wind and solar provide around 50% of total electricity and all renewables provide 80% of electricity.[6] A wind integration study by Nebraska utilities found minimal integration costs and no reliability concerns associated with wind providing 40% of electricity in the Southwest Power Pool.[7]

As another example, in 2014 PJM studied the impacts of obtaining 30% of its electricity from renewables, and found the "PJM system, with adequate transmission and ancillary services in the form of Regulation, will not have any significant issue absorbing the higher levels of renewable energy penetration considered in the study."[8] More recently, PJM completed additional analysis that found very high penetrations of wind energy, including scenarios with wind providing in excess of 75% of energy on its power system on an annual basis, were reliable and resilient. PJM's recent study also found that wind complements natural gas generation to provide resilience against extreme weather, as discussed in Chapter 4.[9]

The Minnesota Department of Commerce found no challenges to integrating 40% wind and solar energy in Minnesota, including a detailed examination of power system dynamics and other reliability services. The study also found no challenges for accommodating the variability associated with wind and solar providing 50% of electricity in the state, though due to time constraints the study did not include a full analysis of power system dynamics in that case.[10] The International Energy Agency also recently released analysis that examined seven large power systems around the globe, including Texas's, and found that all could reliably and cost-effectively obtain 45% of their electricity from renewable energy.[11] NREL's analyses of over 30% renewable energy penetrations in the Eastern and Western U.S. also found no reliability problems or economic barriers.[12] These studies are summarized in this table taken from an NREL report.

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[5] http://www.nrel.gov/docs/fy15osti/63979.pdf. Also see the larger library of studies available at http://variablegen.org/resources/#!/3700/u-s-regional-and-state-studies.
[6] http://www.nrel.gov/analysis/re_futures/
[7] Available at http://www.nepower.org/Wind_Study/final_report.pdf
[8] http://www.pjm.com/committees-and-groups/subcommittees/irs/pris.aspx, page 12
[9] http://www.pjm.com/%7E/media/library/reports-notices/special-reports/20170330-pjms-evolving-resource-mix-and-system-reliability.ashx
[10] https://mn.gov/commerce/industries/energy/distributed-energy/mrits.jsp
[11] http://www.iea.org/Textbase/npsum/GIVAR2014sum.pdf
[12] http://www.nrel.gov/docs/fy11osti/47078.pdf, https://www.nrel.gov/grid/wwsis.htm, https://www.nrel.gov/grid/ergis.html

| Study | Region Scenario, Year | Primary Investigators | Variable Energy Resource Level | Carbon Reduction | Transmission Assumption | Focus of Analysis |
|---|---|---|---|---|---|---|
| PRIS | PJM, 2026 | GE, AWS, EnerNex, Exeter, Intertek, PowerGEM | Multiple 20% and 30% scenarios | 27% to 41% | 2016–17 RTEP plus economic expansion | Broad, including subhourly operations, O&M, cycling, emissions |
| NEWIS | ISO-NE, 2020 | GE, ISO-NE, EnerNex, AWS | Multiple scenarios up to 24% | 30% at 24% wind penetration | 2019 ISO-NE plus overlay from *New England Governors' Renewable Energy Blueprint* | Production simulation and LOLE reliability analysis |
| MRITS | MN and MISO-North/ Central, 2028 | GE, Excel Engineering, MISO, MN utilities and transmission companies | Starting from 28.5% baseline, considered 40% and 50% levels of variable energy resource penetrations | Starting from the 28.5% baseline, some scenarios showed further $CO_2$ reductions of 11.5% to 19% | MTEP 2013, expanded via power flow analysis | Dynamics including transient stability and system strength analysis, production simulation |
| WWSIS | WECC, 2017 and 2022 | NREL, GE, Intertek, 3TIER, others | Up to 35% in WestConnect and 23% in the rest of the Western Interconnection<br>WWSIS-2: 33% in the United States (equivalent to 24% to 26% across the Western Interconnection) | WWSIS-1: Reduced $CO_2$ emissions by 25% to 45%, depending on gas price, across Western Interconnection<br>WWSIS-2: Reduced $CO_2$ by 29% to 34% | Use of current underutilized transmission plus various interstate transmission expansion options | WWSIS-1: production simulation;<br>WWSIS-2: cycling;<br>WWSIS-3: stability and dynamics |
| EFRS | Eastern Interconnection, 2013 | GE, NREL | 25% in Eastern Interconnection (40% in Eastern Interconnection excluding SERC and FRCC) | Wind replaced thermal generation at existing power plant sites | Detailed model of the current system | AC power flow, 60-s dynamic simulations |
| EWITS | Eastern Interconnection, 2024 | NREL, EnerNex, MISO, Ventyx | 30% and multiple 20% scenarios | 19% with 30% wind and no carbon price, 32% with 20% wind plus carbon price | Economic build-out using EGEAS model | Production cost (PROMOD) and power flow (GE-MARS) |
| REF | National | NREL, MIT, others | 50% variable energy resource, 80% total renewable energy | 40% by 2030, 80% by 2050 | Expansion estimated in ReEDS | Capacity expansion and production simulation |

It is reasonable to ask whether these forward-looking studies accurately reflect grid operating realities. Fortunately, the Texas grid operator has answered that question, and in that case found its study actually overestimated the increase in reserve needs that would be caused by wind. In 2013, ERCOT used its real-world grid operating data to validate the results of a 2008 study it had conducted to estimate the impact of higher levels of wind use.[13] The results shown in the report's graphs are summarized in the following table.

| Increase in regulation reserve need per 1,000 MW of wind capacity | 2008 study | 2012 actual data |
|---|---|---|
| Morning | 6.6 | 3.7 |
| Mid-Day | 2.4 | 3 |
| Evening | 10.2 | 1.7 |
| Night | 1.2 | 1.1 |
| **Simple Average** | **5.1** | **2.4** |

Returning to the question of how high can renewable penetration levels go, that is ultimately a question of economics, not reliability. As the use of renewable energy increases, grid operators will simply increase operating reserve levels to ensure that reliability will be maintained to meet reliability standards. As explained below, the incremental cost of these operating reserves is incredibly small, and actually smaller than the integration cost for conventional generation. Moreover, as discussed in the answer to Question

[13] http://www.ercot.com/content/meetings/qmwg/keydocs/2013/1007/GEStudyAnalysis_ERCOTInternalReport.pdf

10 below, cost-effective grid operating reforms can provide large amounts of additional flexibility that will enable even higher levels of renewable use.

It is possible that grid operating challenges could emerge at extremely high levels of renewable use, beyond the levels examined in all wind integration studies to date. However, it should be noted that challenges experienced as a power system approaches 100% wind and solar energy have little bearing on the path forward for U.S. grid operators. While some states are pursuing policies to obtain a very large share of their electricity from renewable energy, those targets are achievable because those states are part of large interstate power systems. No interstate power system is pursuing 100% wind and solar energy, making criticism of the challenges in approaching 100% renewable energy an attack on a strawman argument.

Updating the grid and its operating procedures and holding higher levels of operating reserves will also help address any challenges associated with obtaining the majority of electricity from wind and solar energy, as explained in Chapter 10. The U.S. generation mix is currently evolving towards more flexible resources, which will help address many of those challenges as well. By the time extremely high levels of renewable energy use are reached in the U.S., there will likely also have been technological advances in areas such as demand response, energy storage, electrification of dispatchable demand in the transportation and heating sectors, and even unforeseeable changes that will likely help address these challenges.

It is worth noting that as recently as a decade ago, some utilities and grid operators were concerned about integrating levels of wind that have already been greatly exceeded. With greater operational experience and improvements in technology and operating practices like wind energy forecasting, those concerns have been addressed. This provides reason to be optimistic that improvements in grid operating practices and technology will continue to make the integration of wind energy even easier.

As Bruce Rew, the VP of operations for the Southwest Power Pool, recently explained, "Ten years ago we thought hitting even a 25 percent wind-penetration level would be extremely challenging, and any more than that would pose serious threats to reliability. Now we have the ability to reliably manage greater than 50 percent. It's not even our ceiling. We continue to study even higher levels of renewable, variable generation as part of our plans to maintain a reliable and economic grid of the future…With a footprint as broad as ours, even if the wind stops blowing in the upper Great Plains, we can deploy resources waiting in the Midwest and Southwest to make up any sudden deficits."[14]

Or as the International Energy Agency has noted, "Variability is not just some new phenomenon in grid management. What we found is that renewable energy is not fundamentally different. The criticisms of renewables often neglect the complementarities between different technologies and the way they can balance each other out if spread over certain regions and energy types.

"Grid operators are constantly working to balance available supply with demand – it's what they do. There are always natural variations that cause spikes in demand, reductions in supply or create disturbances in frequency and voltage. Once you see there are a variety of ways to properly manage that variability, you start whittling away at the argument that you always need storage or a megawatt of natural gas backup for every megawatt of renewable energy."[15]

[14] https://www.spp.org/about-us/newsroom/spp-sets-north-american-record-for-wind-power/
[15] http://thinkprogress.org/climate/2011/06/15/245880/top-5-coolest-ways-companies-are-integrating-renewable-energy-into-the-grid/

# 3. Don't we need baseload power?

Instead of using the term "baseload," it is more accurate to talk about the three main services the grid needs to operate reliably: energy, capacity, and flexibility.[16] Cost-effectively obtaining all three services requires a division of labor among a diverse mix of energy sources, as few resources can economically provide all three. For example, baseload resources typically do not provide flexibility, and there can be lower-cost ways of obtaining the energy and capacity provided by baseload. Wind energy primarily adds value to an energy portfolio as a low-cost and non-polluting source of energy, though it also provides some capacity and can provide flexibility when it is economic to do so. Electricity markets efficiently and economically meet power system needs by selecting the resources that are best suited to provide each service through a division of labor.

Reliable and cost-effective operation of the electric grid primarily requires a mixture of three types of services: energy (electricity or MWh), capacity (ability to generate electricity at a certain point in time or MW), and flexibility (a change in MW over some period of time, i.e. the ability to "turn up" or "turn down" electricity generation as needed in response to the aggregate fluctuations of all electricity supply and demand on the power system).

The following table conceptually describes the typical ability of different types of power plants to provide the attributes of energy, capacity, and flexibility. A power plant may specialize in providing one or two of these power system needs, but no power plant excels at economically providing all three.

| | Energy | Capacity | Flexibility |
|---|---|---|---|
| **Wind** | X+ | Some | Can, but is costly |
| **Nuclear** | X | X | None |
| **Coal** | X | X | Little |
| **Natural gas comb. cycle** | X- | X | X |
| **Natural gas turbine** | Too costly | X+ | X+ |
| **Hydroelectric** | Some | X | X |

Because of these differing capabilities, it is important to have a diversity of generation resources on the power system. The most efficient strategy is generally for resources to provide the services they can provide at low cost, and not to use one type of resource to provide all services.

The power system's current trend towards a greater use of renewable energy, gas generation, and demand response appears to be a cost-effective way to meet all three power system needs. Renewable energy is an ideal source of low-cost energy, while gas generation and demand response provide capacity and flexibility at low cost. This division of labor is not new, as explained below.

Nuclear and coal plants, conventionally thought of as "baseload" plants, are remarkably similar to wind plants in that they are primarily energy resources. Like wind, their fuel costs and operating costs are very low. In fact, some grid operators have referred to wind energy as "the new baseload."[17]

[16] https://www.energy.gov/sites/prod/files/2017/01/f34/Maintaining%20Reliability%20in%20the%20Modern%20Power%20System.pdf
[17] https://morningconsult.com/opinions/paradigm-shift-wind-energy-can-new-baseload/

Nuclear and coal plants are capable of providing capacity at a level close to their maximum output. Even so, no power plant can be counted on to reliably provide capacity at its maximum output, as all plants experience mechanical, electrical, or other failures from time to time and must go offline with little notice, as discussed in the next section. For example, nuclear power plants in the Southeastern U.S. have been forced to shut down, some for periods of several weeks, because drought and summertime heat waves raised the temperature of the water in the rivers they rely on for cooling their steam generators. Instances of extreme cold have also forced all types of power plants offline across many regions of the country simultaneously.

Almost all nuclear plants in the U.S. provide no flexibility, and the flexibility provided by some coal plants can be limited. A primary factor is the same reason why most wind plants are not used to provide flexibility: because these resources can provide low cost energy, it typically does not make economic sense for them to forgo energy production so they can provide flexibility.

Without a diverse portfolio, the inflexibility of coal and nuclear plants can present a reliability challenge and is exacerbating the economic challenges of baseload plants that have been undercut by cheap gas generation and are now operating mid-merit.[18]

Electricity supply and demand has always fluctuated, so grid operators have learned to use a division of labor that uses the most flexible resources for flexibility while other resources provide little to no flexibility. All sources of electricity supply and demand are physically aggregated on the power system, with many sources of variability canceling each other out, as explained in Chapter 7. As a result, the aggregate amount of variability that grid operators must accommodate, and the contribution of renewable resources to that variability, is typically quite small. Thus, concern expressed by some that wind plants are not typically operated in a dispatchable way is unfounded. Many types of power plants, including most baseload power plants, are not operated in a dispatchable way today, yet power system reliability is maintained. Like baseload resources, wind can be operated dispatchably, it is just not typically economic to do so.

The terms "intermittent" and "non-dispatchable" more aptly refer to resources like nuclear and coal plants, rather than the renewable resources those terms are commonly but incorrectly used to criticize. Renewable resources are not intermittent as their output changes gradually and predictably, as explained in Chapter 7 below, while large conventional power plants fail instantaneously, taking out 100% of their output without warning. Renewable plants can be and are dispatched to maintain balance in power system supply and demand, as discussed in Chapter 6 below, while many inflexible nuclear and coal plants are truly "non-dispatchable."

A power system with only baseload resources would not be reliable or cost-effective. Moreover, other resources can provide all of the services that are currently provided by baseload generators, in many cases at lower cost than the baseload generators. Baseload resources are not, by themselves, either necessary or sufficient to provide all of the services the power system needs.

Natural gas power plants, particularly combustion turbines, are generally the opposite of nuclear and coal plants, providing significant amounts of flexibility and capacity but typically less energy.[19] This is not

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[18] Joe Bowring of Monitoring Analytics made this point at a PJM meeting on April 19, 2017. http://pjm.com/committees-and-groups/stakeholder-meetings/symposiums-forums/grid-2020-focus-on-resilience-part-1-fuel-mix-diversity-and-security.aspx

[19] http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_6_07_a

because natural gas plants are incapable of generating large amounts of energy, but rather due to the fact that gas power plants typically have higher operating costs because natural gas is generally more expensive than coal.

However, gas plants, particularly combustion turbine (CT) plants, do excel at providing low-cost capacity and at rapidly changing their output. Combined-cycle (CC) natural gas plants are more efficient and thus have lower operating costs than combustion turbine plants, but the tradeoff is that they are generally less flexible. Gas combustion turbines excel at providing capacity at low cost, with a plant's capacity value typically many times higher than its average capacity factor.

Hydroelectric plants are capable of being used for energy, capacity, or flexibility, but there are tradeoffs between these that limit any one dam from providing significant amounts of all three during the same period of time. For example, an increase in the dam's energy and capacity by running at full output decreases its flexibility as it cannot increase output on command, and vice versa. In addition, there are also tradeoffs between energy and capacity, because using up the water stored behind the dam to provide energy limits the ability to provide capacity at a later time.

As the table illustrates, wind excels at providing energy, as its fuel source is free. Wind does provide some capacity and can provide flexibility, although it is typically not the most economic choice if one is primarily seeking to obtain larger amounts of those services.

Renewables do provide valuable amounts of firm capacity for meeting system needs, and this can be accounted for using the same statistical tools planners use for other resources, as discussed in the next chapter.[20] Wind typically provides capacity in a ratio of about one unit of capacity for every two units of average energy output,[21] though a wind plant's exact amount of capacity varies depending on a number of site-specific factors. Wind plants can also rapidly and precisely reduce their output on command, giving them excellent flexibility for reducing supply, and once their output has been reduced they can rapidly increase it. Flexibility to increase power supply is much more costly for wind plants than other types of power plants, as doing so requires holding the plant below its potential output, sacrificing a significant amount of energy that could have been produced for free. However, in certain circumstances in can be economic to do so, and the speed and accuracy of response is higher than almost any other resource.[22]

Our current power system successfully balances the need for energy, capacity, and flexibility. However, the need to reduce harmful impacts from fossil fuel use and diversify our energy mix is driving changes in our energy mix. Because emissions and fuel use are a product of the amount of energy produced, these are not capacity or flexibility challenges, but rather energy challenges. Wind energy, being predominantly an energy resource, is ideally suited to help solve these challenges.

Of course, the grid will continue to need capacity and flexibility. As explained above, wind energy can provide these resources to some extent, although not as well as other types of power plants. Fortunately, natural gas power plants can provide capacity and flexibility at very low cost. Building more natural gas plants or keeping existing fossil-fired power plants around does not significantly harm efforts to reduce fossil fuel use, as power plants that are being used to provide capacity and flexibility only run during the

[20] http://www.nrel.gov/docs/fy08osti/43433.pdf

[21] As discussed in the following chapter, a typical wind plant's average energy output, or **capacity factor**, is 30-50% of the nameplate rating, while a typical **capacity value** (how much of the wind plant's capacity can be counted on for meeting peak electric demand) is 15-25% of the nameplate rating.

[22] http://iiesi.org/assets/pdfs/ieee-power-energy-mag-2015.pdf

small number of hours per year when those services are needed. Demand response, in which electricity consumers reduce or delay non-essential electricity use in response to price signals, can also be used to provide capacity and flexibility at very low cost. Plug-in electric vehicles also have significant potential to serve as sources of flexibility.

Discussions of what power system resources are needed should be focused on the specific services the power system needs and finding the optimal generation mix for obtaining those services at the lowest cost and fuel price risk to consumers.

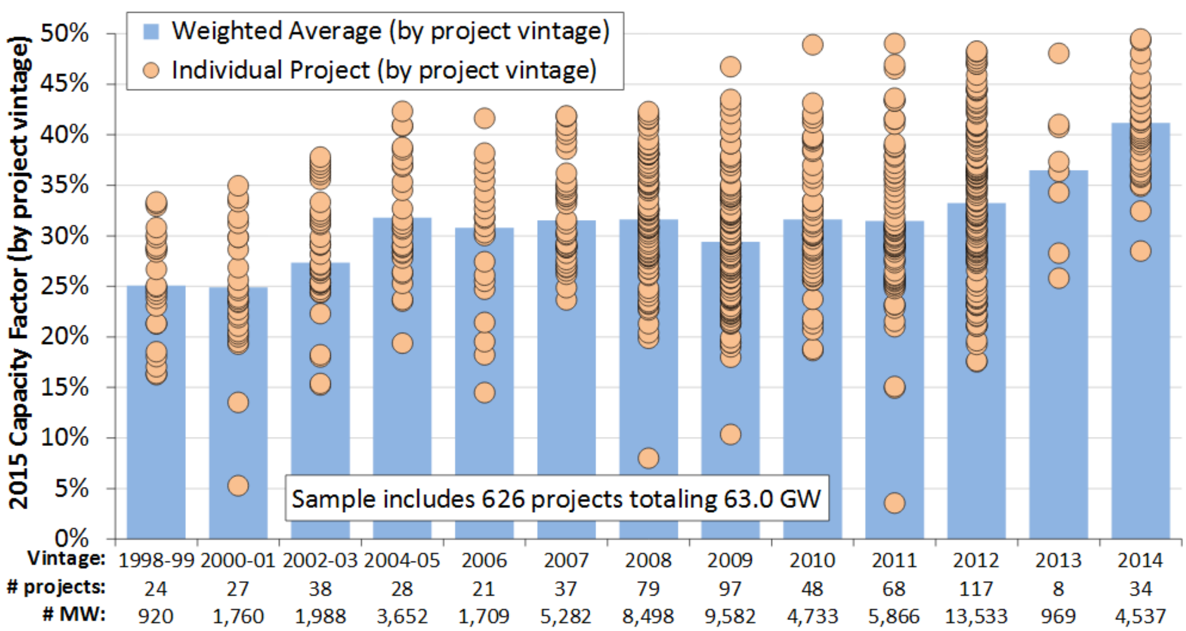
# 4. What happens when the wind doesn't blow?

Other plants provide energy at those times, in the same way that all power plants always back up all other power plants in case they experience an outage. Portfolio diversity is the key to a reliable power system, as no resource is available 100% of the time and all power plants are dependent on all others to back them up. Grid operators have always built more than enough power plant capacity to meet electricity demand, so that a "reserve margin," or cushion is available in case some power plants are not available.

Adding wind power never increases the need for power plants, but rather reduces it. No new capacity is needed to integrate wind, as wind's contribution to meeting system capacity needs is always positive.[23] A power system's capacity need is a total system need driven by peak demand, and the need for capacity never increases and always decreases as wind power is added to the system.

**Understanding capacity factor, capacity value, and operating time**

Capacity factor is the amount of energy produced by a power plant over a period of time, relative to the maximum amount of energy the power plant could have produced if it ran at full output. Thanks to technological advances over the last several years, wind plant capacity factors are rapidly increasing. Longer wind turbine blades, taller turbine towers, and other technology advances have helped drive a two-thirds reduction in the cost of wind energy since 2009 by increasing wind turbine productivity, particularly during lower wind speed periods. The following DOE chart shows capacity factor based on the year in which a wind project was installed, indicating that capacity factors for new wind projects have increased from around 33% as recently as 2012 to around 41% for projects installed in 2015. Many recent wind projects have capacity factors approaching 50%.[24]




[23] See page 2 at http://www.nrel.gov/docs/fy11osti/51860.pdf
[24] https://emp.lbl.gov/sites/default/files/2015-windtechreport.final_.pdf, page 42

Wind's capacity factor compares favorably to capacity factors for other energy technologies.[25] Hydroelectric power plants have capacity factors of around 40% on average, while many fossil power plants have capacity factors in that range or even lower.

Contrary to a common misconception, capacity factor does not indicate the share of time that a wind turbine or power plant is producing power. As of 2013, a typical wind turbine produced some power 83% of the time,[26] though that figure has likely significantly increased due to technological advances since then.

Moreover, because a wind project is composed of many wind turbines spread across a sizeable area with diverse wind resources, a wind project produces power a larger share of the time than an individual wind turbine. Similarly, because all of the wind projects in a grid operating area are spread across an even larger area, in many cases a thousand miles or more, the share of time that wind projects are providing a significant amount of power increases to around 100%. If one expands further to the Interconnect level that actually matters for physically balancing electricity supply and demand, e.g. the East, West, and ERCOT grids in the U.S., wind output becomes even less variable. As a scientific journal article documented, "The number of low-power hours per year declines exponentially with the number of sites being aggregated."[27]

Another commonly confused term is capacity value, which is different from capacity factor. Capacity factor is a measure of energy production, while capacity value is a measure of capacity, which as explained above is the ability of a power system to meet demand. Capacity value is the share of a power plant's nameplate capacity that is statistically available during periods of high demand.

## Capacity value

Wind power does make valuable contributions to meeting the power system's need for capacity. Because of the geographic diversity described in the answer to Question 7 below, a region's aggregated wind energy fleet produces power almost all of the time, particularly when diverse wind resources are aggregated over a very large area. In some regions, such as coastal areas and some mountain passes, wind output is highest when electricity demand is highest. Moreover, as described in more detail below, wind energy is a critical part of creating a more diverse energy mix to protect against the type of "common mode" simultaneous failure that can affect any type of generation, often in unforeseen ways.

Regardless of a region's wind energy output profile, grid operators plan for the capacity value provided by wind like any other resource, and by using the same statistical tools.[28] These tools account for each resource's contribution to the need for on-peak capacity and ensure there is sufficient cushion based on the expected availability of each resource. Wind energy is typically readily incorporated into that calculation.

This calculation accounts for the fact that no power plant is perfectly reliable or controllable, and in fact many resources also fail to produce their maximum capacity when electricity prices are highest. Most thermal power plants experience significant de-rates in their efficiency and maximum output when ambient air temperatures are high, which typically coincides with the time periods when electricity demand and prices are at their highest. DOE data show that the U.S.'s gas, oil, coal, and nuclear fleets have

[25] https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_6_07_a, https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_6_07_b
[26] http://energy.sandia.gov/wp-content/gallery/uploads/CREW2013Benchmark-Presentation-SAND2013-7287P.pdf
[27] http://www.sciencedirect.com/science/article/pii/S0960148116308680, https://arxiv.org/abs/1608.06257
[28] http://www.nrel.gov/docs/fy08osti/43433.pdf

"summer capacities" that are 87%, 89%, 92%, and 95% respectively of their nameplate capacities. In addition, all power plants occasionally experience forced outages that unexpectedly take them offline, and these outages tend to happen with higher frequency during weather extremes that drive high electricity demand. As discussed below, a prime example is the unexpected failure of more than 20% of PJM's conventional power plants during extreme cold and electricity demand in January 2014.[29]

As explained in the next section, grid operators only need a certain amount of flexibility to operate the power system, so it is not necessary for all resources to be operated in a "dispatchable" manner so that their output can be changed to accommodate changes in electricity supply and demand. Wind plants can be operated dispatchably if necessary, but it is not typically economic to do so as other resources can provide that dispatchability at lower cost. This situation is very similar to that of "baseload" conventional resources: because both types of resources can provide low cost energy, it typically does not make economic sense for them to forgo energy production so they can provide flexibility.

It should also be noted that most U.S. power systems currently have a surplus of capacity. This surplus of capacity has primarily been driven by downward revisions in load growth forecasts and the addition of gas capacity for the primary purpose of producing low-cost energy. The following chart from NERC's most recent reliability assessment shows that all regions are expected to have sufficient capacity through 2021, with many regions including PJM experiencing double-digit surpluses above their reserve margin needs.

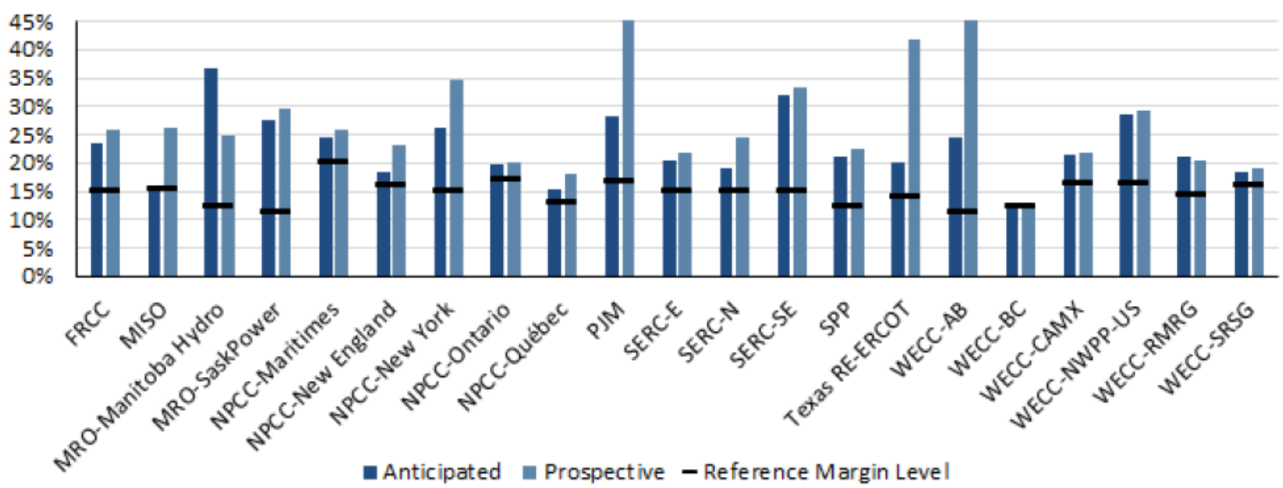



**Figure 1.2: Planning Reserve Margins for Year 5 (2021)**

This capacity surplus is reflected by low prices in capacity markets that indicate capacity is not currently needed or valuable. MISO's most recent capacity market auction resulted in a clearing price of $1.50/MW-day, down from $72.50/MW-day just last year. PJM capacity market prices are also low and expected to continue declining, and PJM has stated that it has studied all announced power plant retirements and found that they do not pose a reliability concern.[30]

For any power systems that do not have surplus capacity, additional capacity can be obtained at relatively low cost through demand response and energy efficiency, the 45+ GW of new gas generation that is

[29] http://www.pjm.com/~/media/library/reports-notices/weather-related/20140113-pjm-response-to-data-request-for-january%202014-weather-events.ashx
[30] http://www.pjm.com/~/media/markets-ops/rpm/rpm-auction-info/2019-2020-base-residual-auction-report.ashx

already being built,[31] or even retaining some existing generating capacity. Retaining capacity is often an attractive option, as doing so only incurs a plant's ongoing fixed costs and does not significantly affect emissions because emissions are a product of energy production, not maintaining capacity. Going forward, energy storage may also emerge as an economic option for providing capacity as well as other ancillary services.

The lower value of capacity relative to energy is confirmed by a method the Department of Energy's Energy Information Administration (EIA) has developed to quantify the value provided by different types of power plants, accounting for differing levels of dispatchability (ability to change generation output), capacity value (ability to meet peak electricity demand), integration costs, and time of energy production. EIA's calculation found that there is only a 10 percent difference, or a difference of about $5/MWh, between the value provided by a wind plant and a more dispatchable gas plant.[32]

Most critically, EIA's calculation shows that wind energy has an average economic value that is much higher than the current cost of wind energy, indicating wind energy provides net benefits for consumers. Of course, this calculation ignores the many other benefits that wind energy provides relative to other energy sources, such as wind plants' lack of fuel price risk, air emissions, water consumption and withdrawals, and other factors.

**Technology advances increasing renewable capacity factors are also increasing capacity value and reducing variability**

As discussed above, today's wind turbines are far more productive than those of just a few years ago. This has reduced costs by improving capacity factors. However, new analysis shows that these advances have had the additional benefits of reducing output variability and increasing wind's capacity value by increasing output during low wind speed periods.[33] Solar is experiencing similar increases in value due to higher capacity factors from higher loading ratios on inverters and the use of tracking systems.

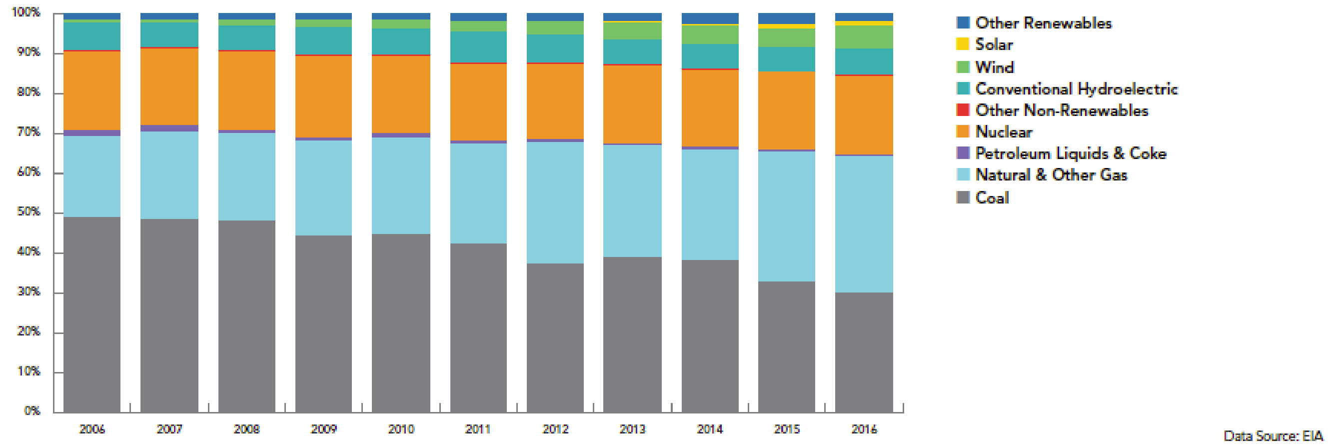
In ERCOT and SPP, which have seen the largest deployment of new wind turbines over the last several years, these advanced turbine designs appear to have noticeably increased wind's contributions during peak demand periods. For the peak demand periods in SPP in 2016, wind generation in the lowest 1 percent of wind output hours increased by a factor of three compared to the lowest output hours in 2013, even though installed capacity increased by only a factor of 1.5. In ERCOT, the independent market monitor noted that there was never less than 3,500 MW of wind available at any point during June 2016, and ERCOT's director of operations noted that wind was generally providing in the range of 4,000 to 5,000 MW during the highest load periods.[34]

**Renewable energy improves power system diversity**

Renewables and gas generation are increasing the diversity of our energy mix, as shown in the following chart of DOE data. Wind works well with other resources to build a balanced, resilient energy mix.

[31] www.nerc.com/pa/RAPA/ra/Reliability Assessments DL/2014LTRA_ERATTA.pdf, page 18
[32] https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf, page 10
[33] http://neon-energie.de/Hirth-Mueller-2016-System-Friendly-Wind-Power.pdf, http://www.mjbradley.com/sites/default/files/Powering_Into_the_Future.pdf
[34] https://www.rtoinsider.com/ercot-board-of-directors-reliability-must-run-30306/

U.S. Electricity Generation Mix over Time




Data Source: EIA

The output patterns of wind and solar make them highly complementary resources. The diurnal and seasonal patterns of wind and solar output are almost perfectly complementary: wind output is typically highest at night and during winter, spring, and fall, while solar output is highest during the summer. Weather patterns tend to cause wind and solar to have complementary output profiles as well - wind output is typically lowest when a high pressure system is present, but solar output tends to be high as high pressure systems are typically marked by cloudless days.

Renewables are also complementary with natural gas generation.[35] Each resource has key attributes that can symbiotically address potential concerns about the other technology's reliability and price stability, as shown in the table below. Natural gas prices are uncertain and variable over the long-term, while wind energy enjoys perfect price stability because its fuel price is always zero. On the other hand, wind output is more variable and uncertain over the grid operating timeframe, while the output of natural gas power plants is highly flexible and dispatchable. Together, wind and gas provide an energy portfolio that better meets the needs of consumers than either resource could provide individually. This finding was confirmed by PJM's recent analysis, which found that portfolios with large amounts of wind and gas generation were reliable and resilient to extreme weather, while many portfolios that did not include significant amounts of wind failed the resiliency test.[36]

| | **Positive Attributes** | **Needs** |
|---|---|---|
| **Wind** | Stable price, high output during winter heating season | Flexible capacity for easiest integration |
| **Gas** | Provides a low-cost source of capacity and flexibility | Hedge against fuel price volatility and gas supply and delivery constraints during heating season |

[35] For more discussion, see http://awea.files.cms-plus.com/WEF_Wind%20Gas%20White%20Paper_031914.pdf
[36] http://www.pjm.com/~/media/library/reports-notices/special-reports/20170330-pjms-evolving-resource-mix-and-system-reliability.ashx

## Renewables are resilient to extreme weather

Given recent events in which many conventional power plants of the same type experienced unexpected simultaneous "common mode" failures, portfolio diversity and resilience is also becoming an increasingly important consideration. PJM's recent analysis of power system reliability included testing the resilience of future energy mixes to extreme events like the 2014 polar vortex. As discussed below, Wind performed quite well during the polar vortex event, while many conventional power plants failed due to the cold weather.[37]

Only around one-third of the reliable energy portfolios PJM analyzed passed the resiliency test.[38] Portfolios with a large amount of wind energy tended to be more resilient because, as PJM noted, wind energy possesses the unique benefit that "unavailability rates for wind are likely to decrease" under a polar vortex event. Said another way, wind energy output tends to be above average when extreme weather causes output from nearly all other energy sources to fall below expectations. That type of negative correlation with the availability of other energy sources is the key to using portfolio diversity to make the power system more resilient.

Interestingly, PJM's results show wind energy complementing gas generation to contribute to resilience in a way that is comparable to the contributions of coal and nuclear power plants. PJM found wind energy played a large role in almost all of the scenarios that maintained resilience while retiring many coal and nuclear power plants.

The need for PJM's study to analyze resilience in addition to reliability highlights the fact that traditional reliability planning measures do not fully capture the risk of many generators being taken offline simultaneously by a single event. Almost all power system planning is based on the invalid assumption that conventional power plant failures are random events, with no correlation between the failure of one conventional power plant and another. As real-world reliability events like the polar vortex have shown, that assumption overstates the reliability of conventional resources by ignoring the risk that many of them will be forced offline simultaneously by correlated, common mode failures. However, wind and solar resources are held to a higher standard, as the impact of weather and other correlated events on their output profile is taken into account in analyses of their capacity value.

The portfolio diversity benefits of wind energy were particularly pronounced during the polar vortex event as unexpected generator failures and fuel price spikes caused electricity prices to soar as many regions faced record winter demand. Wind energy continued to produce at or above expectations with no exposure to fuel price increases. The consumer savings from stably-priced wind generation totaled at least $1 billion over two days in PJM alone, and wind helped to avert potentially severe reliability problems.[39] During another cold snap in early January 2015, wind energy similarly provided record amounts of power to grid operators in the Central and Eastern U.S. as they faced high demand due to extreme cold.[40] These events illustrate how wind plays a critical role in protecting consumers and reliability by diversifying our energy mix:

[37] http://www.nerc.com/pa/rrm/January%202014%20Polar%20Vortex%20Review/Polar_Vortex_Review_29_Sept_2014_Final.pdf
[38] http://www.pjm.com/~/media/library/reports-notices/special-reports/20170330-pjms-evolving-resource-mix-and-system-reliability.ashx
[39] http://awea.files.cms-plus.com/AWEA%20Cold%20Snap%20Report%20Final%20-%20January%202015.pdf
[40] http://www.utilitydive.com/news/wind-generation-hits-records-mitigates-price-spikes-during-cold-snap/351057/

- Early on January 6, 2014, 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."[41]
- On January 7, 2014, wind output was very high when the New York grid operator faced record winter demand.[42]
- On January 22 and 23, 2014, PJM electricity and natural gas prices skyrocketed to 10-50 times normal due to extreme cold. Wind output was above 3,000 MW, saving consumers millions.[43]
- 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.[44] The state grid operator noted that this wind output allowed it to avoid calling an energy emergency alert.[45]

NERC's Polar Vortex Review identified fuel deliverability issues, natural gas pipeline outages, gas service interruptions, and frozen electricity and gas equipment as key factors for generator unavailability during the vortex, which threatened system reliability in multiple regions.[46] While wind turbines did occasionally experience outages due to the cold weather, the vast majority of the generators that failed to perform were conventional power plants.

The story was the same in February 2011, when ERCOT noted wind energy's role in keeping the lights on when a cold snap caused many conventional power plants to fail.[47] Notable examples of wind improving reliability by increasing the diversity of the energy mix have also occurred in other countries.[48]

The portfolio diversity benefits of renewable energy can also be seen in how wind and solar helped to cost-effectively maintain electric reliability during the California drought, making up for the vast majority of the 1/3 decline in hydroelectric output.[49]

While the drought imposed major costs on the state's agriculture and Californians in general, the drought also posed challenges for electric reliability because various parts of the electricity system are dependent on water. The California grid operator expected 1,370 MW to 1,669 MW (18-22 percent) of the state's 7,666 MW of hydroelectric power plants to be unavailable to provide energy to meet peak system demands during the summer of 2014.[50] Moreover, the grid operator noted that 1,150 MW of the state's thermal power plants were at risk of having cooling water supply curtailments that summer.

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[41] http://www.nppd.com/2014/nebraska-customers-set-time-winter-peak-nppd/

[42] 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

[43] http://www.pjm.com/markets-and-operations/ops-analysis.aspx

[44] http://www.caiso.com/Documents/ISOissuesStatewideFlexAlert.pdf

[45] SNL Energy article, Christine Cordner, "CAISO: Wind, demand response helped avoid February emergency alert," March 21, 2014

[46] http://www.nerc.com/pa/rrm/January%202014%20Polar%20Vortex%20Review/Polar_Vortex_Review_29_Sept_2014_Final.pdf

[47] Available at: http://www.texastribune.org/2011/02/04/an-interview-with-the-ceo-of-the-texas-grid/

[48] http://www.pjm.com/~/media/library/reports-notices/special-reports/20170330-pjms-evolving-resource-mix-and-system-reliability.ashx, http://thinkprogress.org/climate/2014/08/12/3470140/wind-power-nuclear/

[49] https://www.eia.gov/electricity/data/browser/

[50] http://www.caiso.com/Documents/2014SummerAssessment.pdf

Renewable energy helped with this challenge in two direct ways. One of wind energy's most overlooked benefits is that it requires virtually no water to produce electricity, while almost all other electricity sources evaporate tremendous amounts of water. In 2008, the nation's thermal power plants consumed 1 to 2 trillion gallons of water.[51] By displacing generation from these conventional power plants, U.S. wind energy currently saves around 87 billion gallons of water per year, the equivalent of 266 gallons per person or 657 billion bottles of water.[52]

In addition to directly offsetting freshwater consumption at thermal power plants, wind energy helps combat the impacts of drought by allowing grid operators to save hydroelectric energy (in the form of water behind dams) until they need it to meet grid reliability needs. A MWh of wind energy almost always displaces a MWh that would have been produced by a fossil-fired power plant, though sometimes grid operators use wind energy to store additional water behind dams where it can be used later to displace fossil fuel generation. While a number of complex factors affect how dams use their water resources, the abundant supply of renewable energy likely alleviated pressure on the operators' need to use water to produce electricity, helping them maintain reservoir levels so they could continue producing power and providing grid reliability services. In addition, in most regions the variability of the wind energy resource from year-to-year is much lower than that of the hydroelectric resource, so adding wind energy improves the reliability and resilience of the electricity system, particularly in regions that obtain a large share of their electricity from hydropower.

**On-site fuel supply**

On-site fuel supply is not a silver bullet for reliability, as all energy sources are vulnerable to interruptions. If on-site fuel is deemed valuable, gas generators can be converted to dual-fuel capability or firm gas transportation. New resources like demand response and energy storage are also immune to most of these challenges.

In addition to the polar vortex event, PJM's report discusses other weather events and other common mode failures that have affected many power plants, including those with on-site fuel. Examples include droughts that have limited fossil and nuclear power plants' access to cooling water. Droughts and sustained high temperatures in various parts of the U.S. have forced fossil and nuclear plants to operate at reduced output or even go offline, while the recent drought in California greatly reduced the state's hydroelectric output.[53] These high temperature and drought events also typically coincide with the periods of highest electricity demand. Wind energy and solar photovoltaics continued to generate as expected during these events, as they require no water to operate.

As also noted above, thermal generators are frequently de-rated and lose efficiency during heat waves, due to the physical principle that the power produced by a thermal power plant decreases as the temperature difference between the combustion side of the turbine and the outside temperature decreases.

Fueled resources also face challenges of fuel delivery. Most notable are disruptions to gas supply and delivery during periods of extreme cold and high demand, but coal plants are also vulnerable. For example, several years ago many coal power plants in the Midwest were nearly forced offline when rail shipments of coal were unable to get through because of railroad infrastructure congestion primarily

[51] http://www.ucsusa.org/assets/documents/clean_energy/ew3/ew3-freshwater-use-by-us-power-plants.pdf
[52] http://www.awea.org/wind-and-water
[53] http://www.transmissionhub.com/articles/2012/01/ercot-drought-could-cause-problems-with-power-grid-in-2013.html, http://www.climatecentral.org/blogs/heat-and-drought-pose-risks-for-nuclear-power-plants,

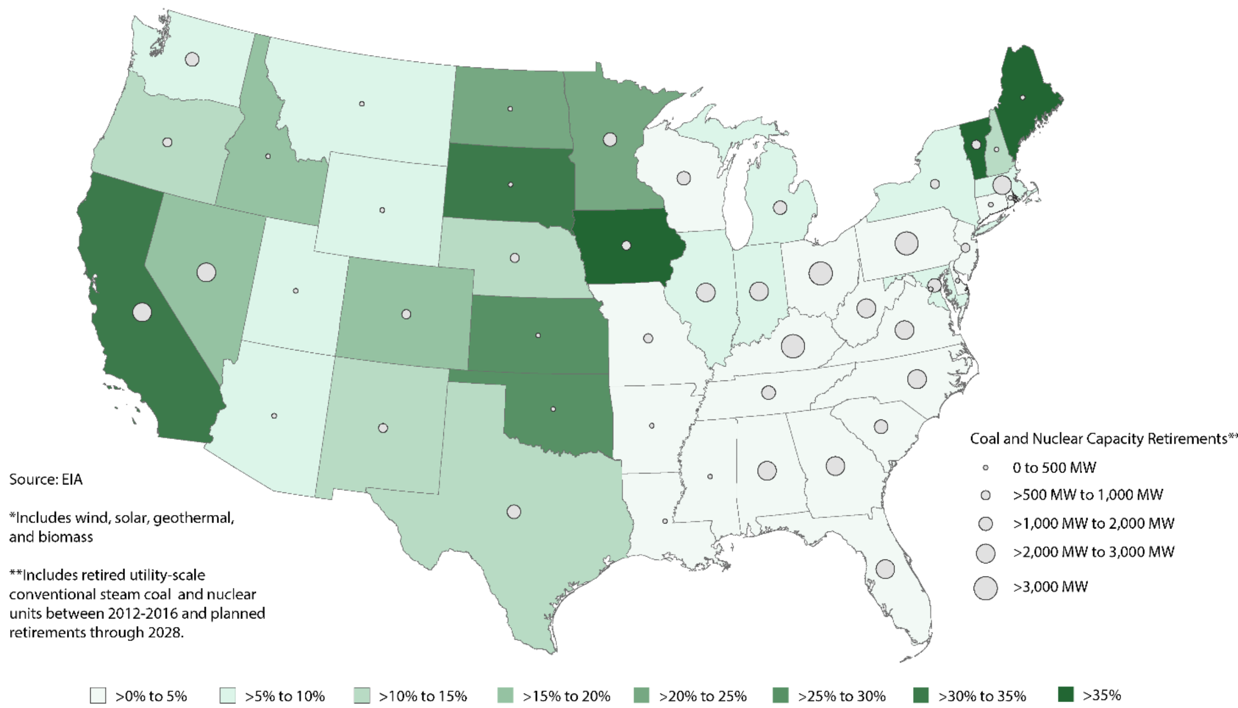
caused by a spike in oil shipments via rail from the Bakken shale area. For power plants that receive coal by barge, constraints can also come into play during periods of drought. Coal piles at power plants can also freeze during cold and wet conditions.

# 5. Why are coal and nuclear plants facing economic challenges?

Energy company regulatory filings and public statements,[54] government data,[55] and other experts[56] agree that low natural gas prices and flat electricity demand, and not policies to promote renewable energy, are the main challenge facing coal and nuclear generators.

Some of the clearest evidence that renewable energy is not the main factor driving other energy sources' market woes can be seen just by looking at where coal and nuclear power plants are retiring. Most retiring coal and nuclear plants are in areas that have little to no renewable generation, as shown below.

Recent and Planned Coal and Nuclear Retirements
and 2016 U.S. Renewable Energy* Share of Electricity Generation, by State



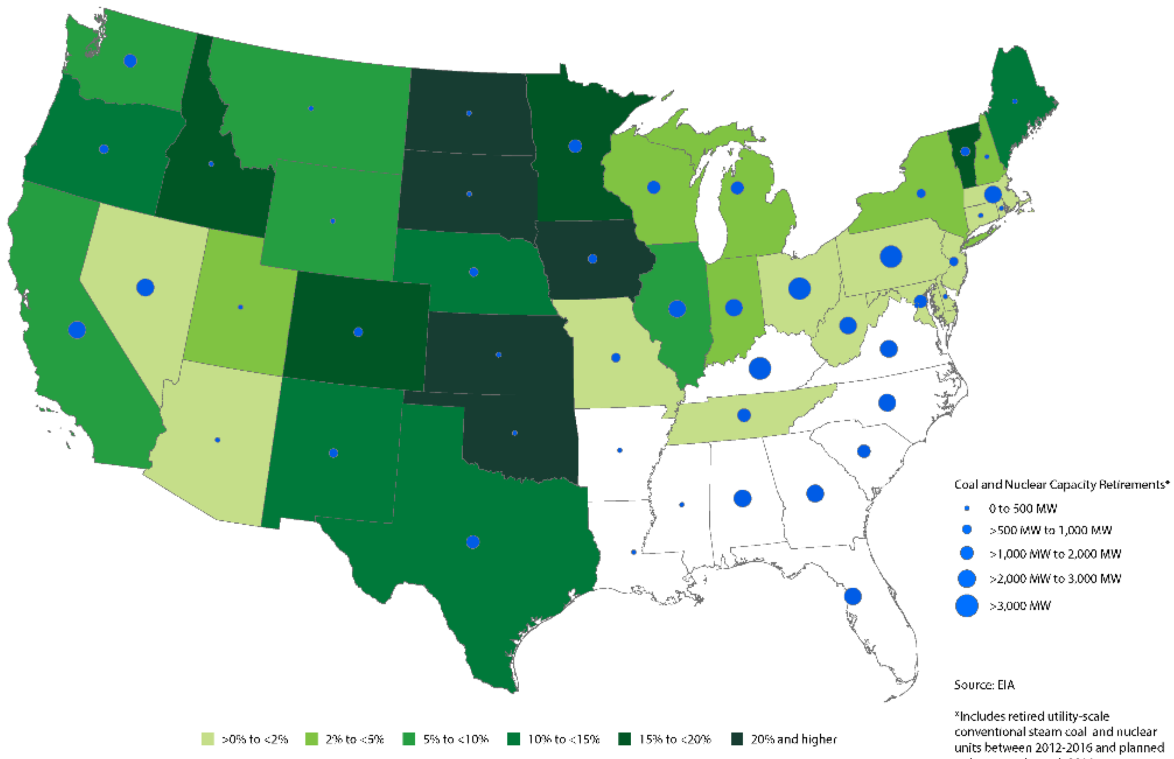

[54] For example, see "The decision by the utility owners of [Navajo Generating Station] is based on the rapidly changing economics of the energy industry, which has seen natural gas prices sink to record lows and become a viable long-term and economical alternative to coal power." http://www.srpnet.com/newsroom/releases/021317.aspx
"Gas prices by far have the most dominant effect on the unregulated power sector in the US," Moody's said in a March 31, 2017, report. "Low natural gas prices have devastated most of the US merchant power sector because gas-fired power plants often serve as the marginal plant during times of peak power demand," Moody's said. "Lower natural gas prices have effectively driven down wholesale power prices for all generators, regardless of whether they are using natural gas, coal, nuclear power or renewable resources to generate their electricity."
https://www.snl.com/web/client?auth=inherit#news/article?id=36007486&KeyProductLinkType=0&cdid=A-36007486-11568

[55] https://www.eia.gov/todayinenergy/detail.php?id=31172

[56]http://theconversation.com/are-solar-and-wind-really-killing-coal-nuclear-and-grid-reliability-76741,http://energypolicy.columbia.edu/sites/default/files/energy/Center%20on%20Global%20Energy%20Policy%20Can%20Coal%20Make%20a%20Comeback%20April%202017.pdf

At the same time, the wind-heavy interior region of the U.S. has seen few coal retirements, even though coal provides a larger share of the electricity mix in that area.

Recent and Planned Coal and Nuclear Retirements
and 2016 U.S. Wind Energy Share of Electricity Generation, by State

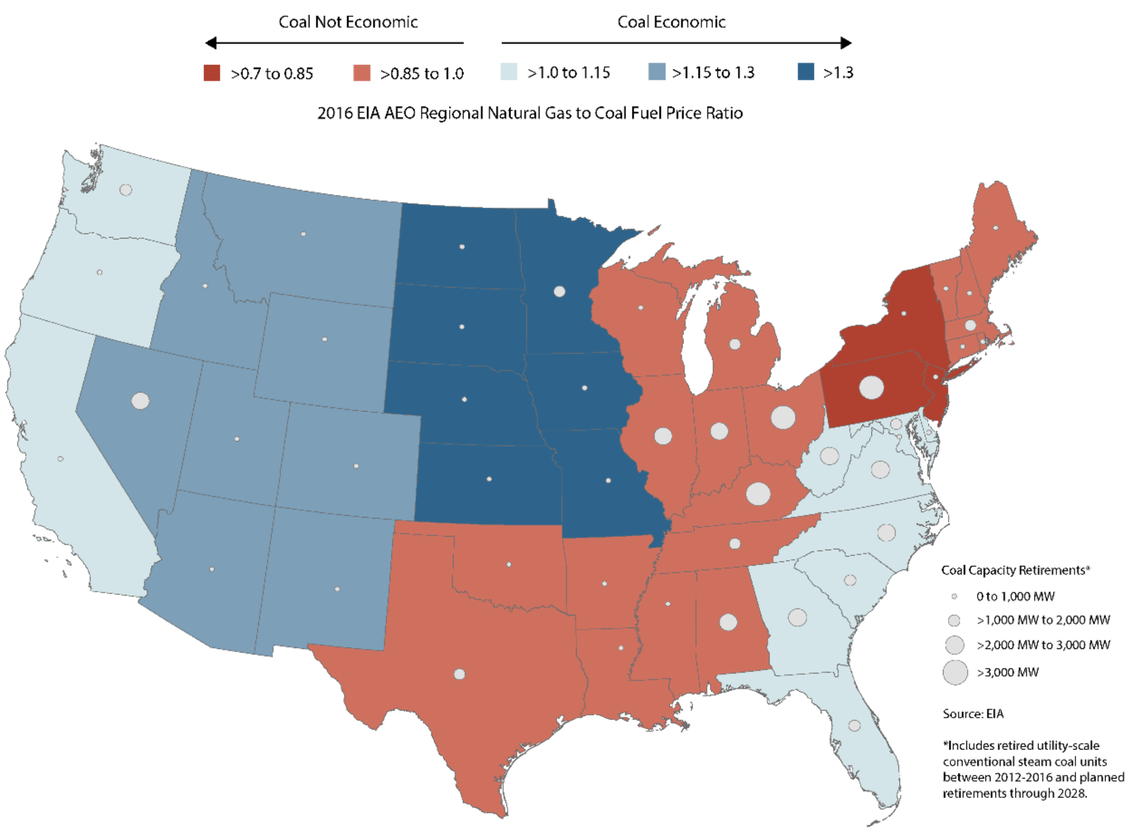



Source: EIA

*Includes retired utility-scale conventional steam coal and nuclear units between 2012-2016 and planned retirements through 2028.

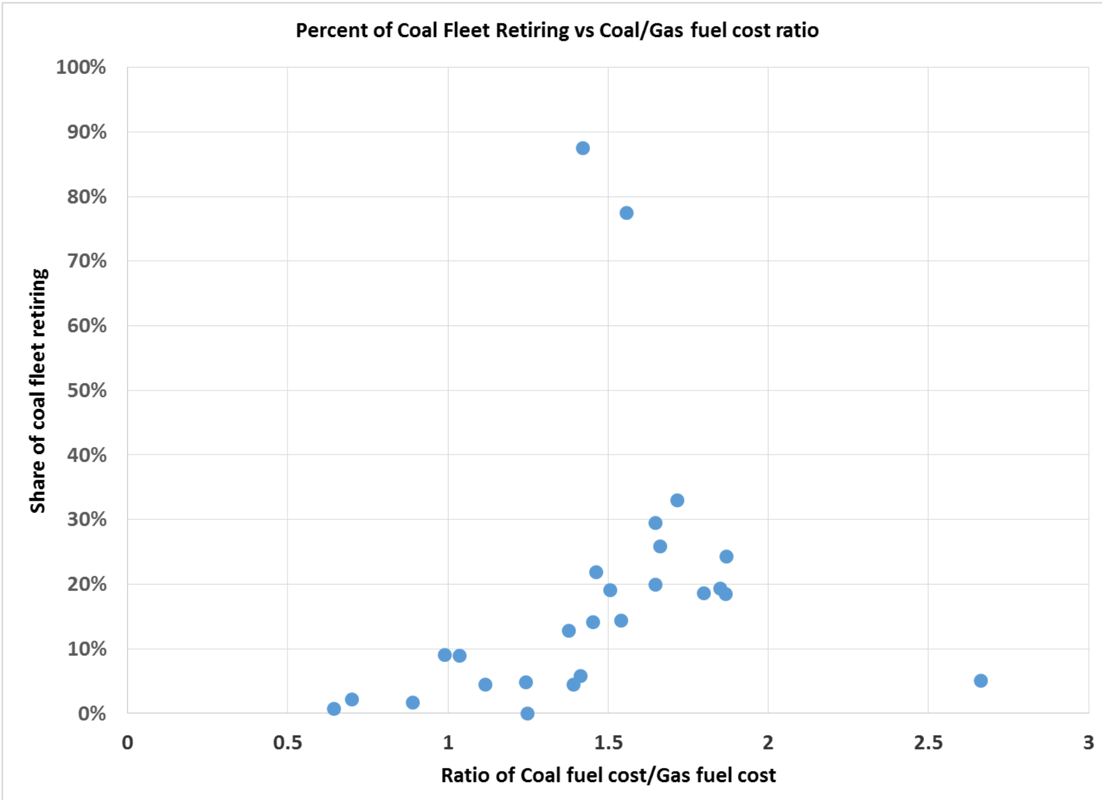
Rather, the primary factor driving power plant retirements appears to be low-cost shale gas production undercutting relatively high cost Appalachian and Illinois Basin coal in the Eastern U.S., as shown below. In the regions shaded red in the map, the fuel cost of producing electricity from natural gas is significantly lower than the fuel cost of coal power plants, explaining why utilities in those regions are moving from coal to natural gas generation.[57]

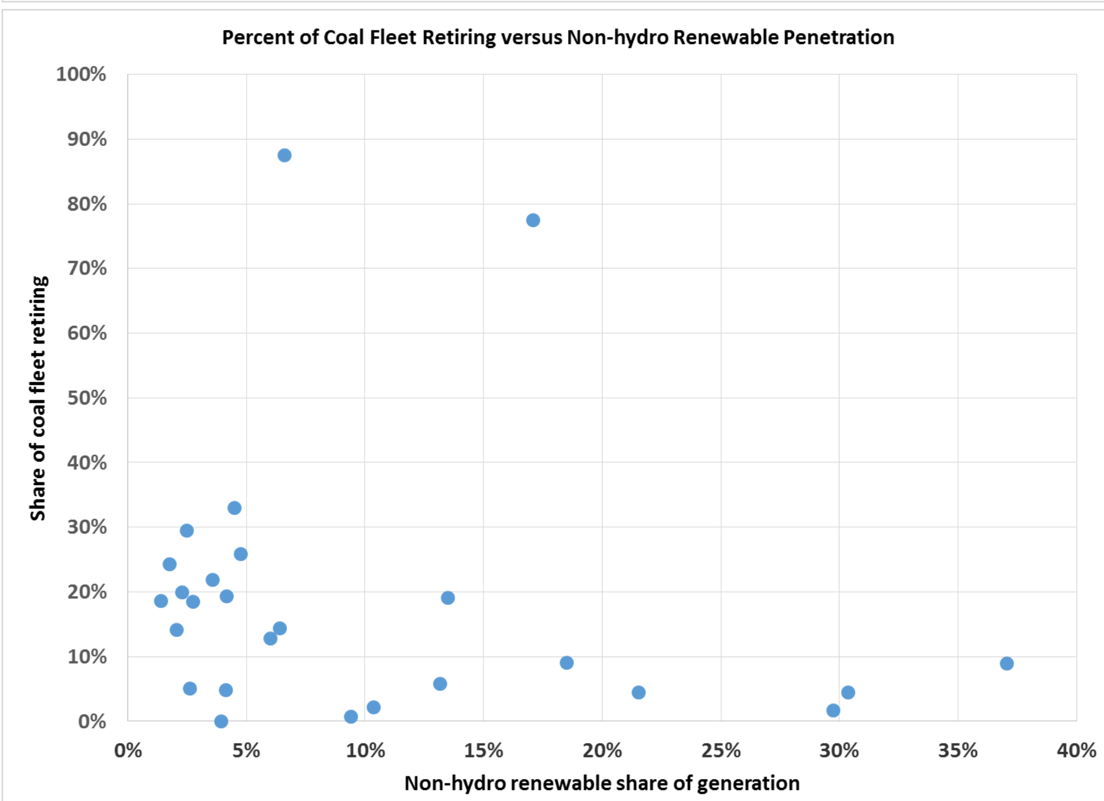
Recent and Planned Coal Retirements and Economics of Coal versus Natural Gas, by Region




Plotting the price of coal fuel against the price of gas fuel by state in the first chart below shows that, unsurprisingly, the states where coal is uneconomic relative to gas have seen the most coal retirements.[58] As shown in the second chart, most renewable-heavy states have below average coal retirements, while most low renewable-use states have above average coal retirements, contradicting the claim that renewables are a primary factor causing coal plant retirements.[59]

[57] EIA AEO 2017 regional electric sector fuel prices for 2016, EIA coal retirement data
[58] EIA 2015 coal and gas electric sector delivered price data, multiplied by EIA national average heat rates. Only states for which both coal and gas price data are available are shown.
[59] 2016 EIA generation data used for renewable penetration.


Percent of Coal Fleet Retiring vs Coal/Gas fuel cost ratio
Share of coal fleet retiring
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.5
1
1.5
2
2.5
3
Ratio of Coal fuel cost/Gas fuel cost


Percent of Coal Fleet Retiring versus Non-hydro Renewable Penetration
Share of coal fleet retiring
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0%
5%
10%
15%
20%
25%
30%
35%
40%
Non-hydro renewable share of generation

Wind has a relatively small impact on the economics of other power plants because wind energy rarely sets the electricity market price. Fossil resources almost always set the market clearing price across wholesale electricity markets, while wind almost never does. Market-wide in MISO in 2015, wind set electricity prices only 1% of the time, versus natural gas power plants 76% and coal power plants 23% of the time.[60] In PJM in 2016, wind setting the market-wide clearing price only changed prices by $0.05/MWh, or 0.2% (1/500th) of total prices, versus 45% for coal and 27% for natural gas.[61]

As a result, the price of fossil fuels has a direct impact on electricity prices, while wind does not.[62] Importantly, this also means that renewable incentives like the production tax credit (PTC) are not directly factored into electricity market prices, while subsidies for fossil generators that do set the market price are factored into wholesale prices. Thus, fossil subsidies tend to have a far larger impact on electricity market prices.

It is true that adding any low-cost source of energy to the power system reduces the price of electricity by pushing the supply curve out.[63] Pushing the supply curve out in this way is a market-based outcome that occurs for any low-cost form of energy, whether nuclear, hydropower, or even coal, and is beneficial for consumers. In fact, utilities, large corporations, and others routinely explain that they buy wind energy precisely because it allows them to diversify their energy portfolio with a low-cost, stably-priced source of energy.

Regardless of whether wind or solar plants receive tax credits or not, they have the same impact on prices because they are always dispatched first due to their zero fuel cost. Removing incentives for renewable generation would not have a significant direct impact on power prices. As discussed further in Chapter 12, occasionally wind or solar do set market clearing prices, but that is typically due to localized transmission constraints on remote parts of the grid where there are typically few, if any, other generators, so there is little to no impact on the economics of other resources.

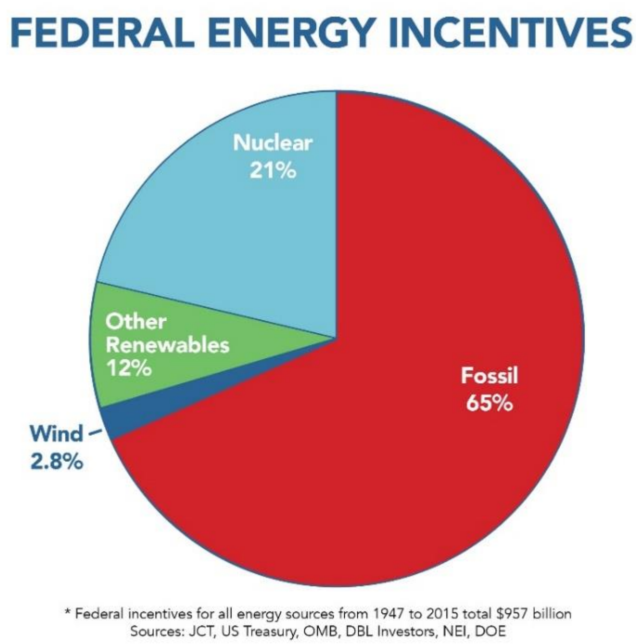
Negative electricity prices are rare, and many instances are not caused by wind energy.[64] Nuclear, hydroelectric, and coal power plants cause many instances of negative prices, mostly because the inflexibility of these generators prevents them from reducing their output during periods of low electricity demand. Some coal plants offer electricity at negative prices because they face economic penalties if they do not take the minimum amount of coal required under coal delivery contracts.[65]

Wind energy and the renewable PTC are compatible with well-functioning electric power markets. The myth that policies to promote wind have a significant impact on other generation was dismissed as a "distraction" by former Federal Energy Regulatory Commission Commissioner Norris, based on evidence that AWEA put forward in a March 2014 report that he called "compelling."[66] That report explained that wind's impact is market-driven, comparable to that of any low-cost generation, and small compared to

[60] https://www.misoenergy.org/Library/Repository/Report/IMM/2015%20State%20of%20the%20Market%20Analytical%20Appendix.pdf, page A-6
[61] http://www.monitoringanalytics.com/reports/PJM_State_of_the_Market/2016/2016-som-pjm-volume2.pdf, page 161
[62] http://theconversation.com/are-solar-and-wind-really-killing-coal-nuclear-and-grid-reliability-76741
[63] The impact on additional low-cost energy supply on electricity market prices is currently small because many gas generators are competitive with coal generators due to low natural gas prices, flattening the supply curve.
[64] In the ERCOT North zone in the second half of 2016, prices were negative only 0.7% of the time. 99% of those negative prices were negative by only a few dollars, indicating they were not set by PTC wind projects. http://mis.ercot.com/misapp/GetReports.do?reportTypeId=13061&reportTitle=Historical%20RTM%20Load%20Zone%20and%20Hub%20Prices&showHTMLView=&mimicKey
[65] For more details, see http://www.aweablog.org/negative-prices-still-rare-mostly-caused-by-other-energy-sources/
[66] http://ferc.gov/media/statements-speeches/norris/2014/05-15-14-norris.asp; AWEA's report and follow-up analysis is available at http://www.aweablog.org/blog/post/ferc-commissioner-exelon-attacks-on-ptc-a-distraction

other factors. Moreover, any effect of negative pricing on other generation has been virtually eliminated by new transmission, and that will continue to be the case if workable policies to pro-actively plan and pay for transmission are implemented.

It is true that incentives for the deployment of renewable energy have increased renewable generation, as was the intent of Congress and states in enacting those policies. This does reduce prices by pushing the supply curve out, as described above. However, one must keep in mind that all energy sources have received and continue to receive large amounts of federal and state support. Wind only accounts for 3% of federal cumulative energy incentives, while nuclear and fossil energy sources that also push the supply curve out have accounted for a combined 86% of federal energy subsidies.[67]




While many fossil subsidies are written into the permanent tax code, the wind tax credit has already begun to phase out and the solar tax credit will begin to phase down in the near future. While state renewable standards continue to be an important driver of renewable energy in many regions, some of the largest deployments of wind in recent years have occurred in states like Texas, Oklahoma, Kansas, and Iowa that have already met their renewable standards.

For those concerned about the economic viability of coal and nuclear power plants, focusing on federal and state renewable policies that are working as intended would be misguided. However, the following policies would help provide real solutions for these power plants while also improving market efficiency and reducing costs for consumers:

- Transmission – Upgrading America's infrastructure by putting in place workable policies to plan, pay for, and permit transmission should be a primary focus of policy makers. This helps all low-cost forms of generation, whether renewable or baseload, by eliminating congestion that is depressing power prices in generation pockets and allowing those low-cost generators to reach consumers. In dismissing previous attacks on wind and its tax credit as a "distraction," Federal Energy Regulatory

[67] For data sources, see http://www.aweablog.org/14419-2/

Commissioner John Norris explained that "Transmission development is the better, and more proactive, solution."[68]

- Markets – Better use of the existing grid through more efficient dispatch and the expansion of markets will lower costs and more fairly allow all resources to compete.
- Market design – Uplift costs and other costs associated with producing electricity should be brought into the energy markets, which will raise prices and fully compensate resources. Further, seams issues related to pricing and transacting between ISOs must be addressed. Markets must become more precise in their procurement and compensation of reliability and ancillary services, and barriers to entry must be removed. Wind and other non-traditional resources can provide these services but getting the market rules right is critical.

[68] https://ferc.gov/media/statements-speeches/norris/2014/05-15-14-norris.asp

# 6. What about the reliability services provided by conventional generation?

As wind energy has grown to provide a larger share of our electricity mix, wind turbine technology has matured so that modern wind and solar plants are able to provide grid reliability services as well as or better than conventional generators. Grid reliability services include various "ancillary services" that are necessary for the efficient and reliable operation of the power system, such as voltage and reactive power regulation and the ability to ride-through and respond to grid disturbances.

Wind and solar plants meet the same or higher reliability services standards as conventional power plants. The wind industry has pushed for more stringent standards as it understands that for the industry to continue its long-term growth, wind plants must contribute to power system reliability. In 2005 the wind industry supported the introduction of a stringent requirement for wind plants to ride-through voltage and frequency disturbances.[69] This standard is more stringent than the standard that applies to conventional power plants, and many conventional power plants cannot meet the standard that applies to wind. Last year AWEA supported the more stringent reactive power requirements in FERC Order 827, and did not oppose requiring wind plants to have primary frequency response capability in a recent FERC rulemaking.[70]

Wind turbines and solar plants have power electronics and output controls that enable fast and accurate voltage and frequency control, in many cases an order of magnitude faster than conventional power plants.[71] As the North American Electric Reliability Corporation (NERC) has stated, "Modern wind turbine generators can meet equivalent technical performance requirements provided by conventional generation technologies with proper control strategies, system design, and implementation."[72] Regarding reliability concerns, NERC has noted that "This issue does not exist for utility-scale wind energy, which offers ride-through capabilities and other essential reliability services."[73] Detailed analyses show that essential reliability services will be maintained at high renewable levels in both the Eastern and Western Interconnections.[74] Wind plants can provide frequency response, inertial response, active power control, voltage and frequency ride-through, voltage and reactive power control, and other grid reliability needs:

| Reliability service | Wind | Conventional generation |
|---|---|---|
| **Ride-through** | - Excellent voltage and frequency ride-through per FERC Order 661A requirements<br>- Power electronics electrically separate wind turbine generators from grid disturbances, providing them with much greater ability to remain online through disturbances | - Many cannot match wind's capabilities or meet Order 661A ride-through requirements |
| **Reactive and voltage control** | - Wind turbine power electronics provide reactive and voltage control equivalent to that of conventional generators[75] | - Provides |

[69] https://www.ferc.gov/EventCalendar/Files/20051212171744-RM05-4-001.pdf
[70] https://www.ferc.gov/whats-new/comm-meet/2016/061616/E-1.pdf, https://www.ferc.gov/whats-new/comm-meet/2016/111716/E-3.pdf
[71] https://www.caiso.com/Documents/UsingRenewablesToOperateLow-CarbonGrid.pdf, http://www.nrel.gov/docs/fy14osti/60574.pdf
[72] http://www.nerc.com/files/ivgtf_report_041609.pdf, page 22
[73] http://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/2014LTRA_ERATTA.pdf at 15
[74] http://www.nrel.gov/docs/fy15osti/62906.pdf, http://www.nrel.gov/docs/fy13osti/58077.pdf
[75] http://www.nerc.com/files/ivgtf_report_041609.pdf, page 22, "As variable resources, such as wind power facilities, constitute a larger proportion of the total generation on a system, these resources may provide voltage regulation and

| | | |
|---|---|---|
| | - Power electronics can provide reactive power and voltage control even when the wind plant is not producing power[76]<br>- AWEA supported stringent reactive power requirement in FERC Order 827 | |
| **Active power control** | - Can provide extremely fast response in seconds, far faster than conventional generation[77]<br>- Like other generators, wind will provide this response when it is economic to do so<br>- Xcel Energy sometimes uses its wind plants to provide some or all of its frequency-responsive automatic generation control[78] | - Like wind, many coal and nuclear generators do not provide active power control for economic reasons, though they technically can. |
| **Primary frequency response** | -Adding wind can help system frequency response by causing conventional generation to be dispatched down[79]<br>-Wind can provide frequency response, but it is typically more costly for it to do so than for other resources as it requires curtailing wind generation in advance[80]<br>-A market-based solution procures frequency response from the lowest cost resources<br>-NERC analysis found there is no correlation between level of renewable generation and primary frequency response on the power system[81] | - Changes in conventional generator operating procedures have greatly reduced frequency response[82]<br>- Only 70-75% of generators have governors that are capable of sustaining frequency response for more than one minute, and about half of conventional generators have controls that may withdraw sustained frequency response for economic reasons[83]<br>- "Only 30% of the units on-line provide primary frequency response. Two-thirds of the units that did respond exhibit withdrawal of primary frequency response." So, "Only 10% of units on-line sustain primary frequency response."[84]<br>- The cost of providing and sustaining frequency response is very low for a conventional generator, so a market-based solution would incentivize the needed frequency response at low cost |
| **Inertial response** | -Can provide with no lost production by using power electronics and the inertia of the wind | -Provides |

reactive power control capabilities comparable to that of conventional generation. Further, wind plants may provide dynamic and static reactive power support as well as voltage control in order to contribute to power system reliability."

76 http://energy.sandia.gov/wp/wp-content/gallery/uploads/ReactivePower_IEEE_final.pdf

77 http://www.nrel.gov/docs/fy14osti/60574.pdf "Wind power can act in an equal or superior manner to conventional generation when providing active power control, supporting the system frequency response and improving reliability."

78 http://iiesi.org/assets/pdfs/ieee-power-energy-mag-2015.pdf

79 http://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/2014LTRA_ERATTA.pdf at page 29, "However, by causing conventional generators to have their output dispatched down, wind and solar generation can increase generator headroom and, therefore, the amount of total frequency response being provided."

80 *Id.*, "Wind resources can offer inertia and frequency response, depending on the design attributes of a given wind plant."

81 http://www.nerc.com/comm/PC/Agenda%20Highlights%20and%20Minutes%202013/PC%20Presentations%20-Final.pdf, page 205

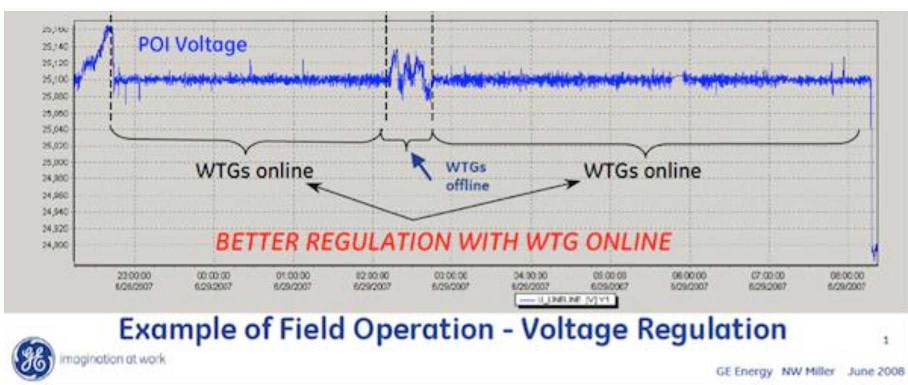
82 http://www.nerc.com/files/FinalFile_Comments_Resp_to_Sept_Freq_Resp_Tech_Conf.pdf

83 http://www.nerc.com/docs/pc/FRI_Report_10-30-12_Master_w-appendices.pdf, pages 32-33

84 *Ibid.,* page 37

| | | |
|---|---|---|
| | turbine rotor; this capability is commercially available but not widely deployed because there is no payment for any resource to provide this service[85] | |
| **Increases need for operating reserves, integration cost** | - Very small impact on total reserve need and integration cost | -Contingency reserve needs and costs are quite large |

As documented in the footnotes in the table above, many NERC reports discuss the capabilities of renewable energy to provide these reliability services. For example, NERC reports have documented that wind and solar "may provide voltage regulation and reactive power control capabilities comparable to that of conventional generation."[86] All modern wind turbines have sophisticated power electronics that allow the turbine to provide significant voltage and reactive power control at all times, even when the wind turbine is not producing electricity. As compellingly illustrated by the actual power system data presented in the chart below,[87] wind turbines can significantly improve power system voltage stability, indicated by the fact that power system voltage is much better regulated when wind turbine generators (WTGs) are online than when they are not.




Thanks to their power electronics, wind plants also meet a higher standard for and far exceed the ability of conventional power plants to "ride-through" power system disturbances, which is essential for maintaining reliability when voltage and frequency disturbances occur, such as when large conventional power plants experience forced outages.[88] This reliability service is critical, as the failure of conventional power plants to

[85]http://web.mit.edu/windenergy/windweek/Presentations/GE%20Impact%20of%20Frequency%20Responsive%20Wind%20Plant%20Controls%20Pres%20and%20Paper.pdf; http://www.nerc.com/files/ivgtf_report_041609.pdf, page 18, "In common with Type 3 wind turbine-generators, this decoupling means that in the standard design inertial response can be a programmed feature during a frequency event and the Type 4 wind turbine-generators can provide comparable inertial response/ performance to a conventional generator."

[86] NERC, "Accommodating High Levels of Variable Generation," April 2009, available at http://www.nerc.com/docs/pc/ivgtf/IVGTF_Report_041609.pdf, page 22.

[87] Miller, N., GE Presentation, June 2008.

[88] FERC Order 661A provides strict ride-through requirements for wind turbines, requirements that do not apply to conventional generators and that many conventional generators are unable to meet. http://www.ferc.gov/whats-new/comm-meet/052505/E-1.pdf

ride-through grid disturbances has played at least a contributing role in several recent blackouts and reliability events.[89]

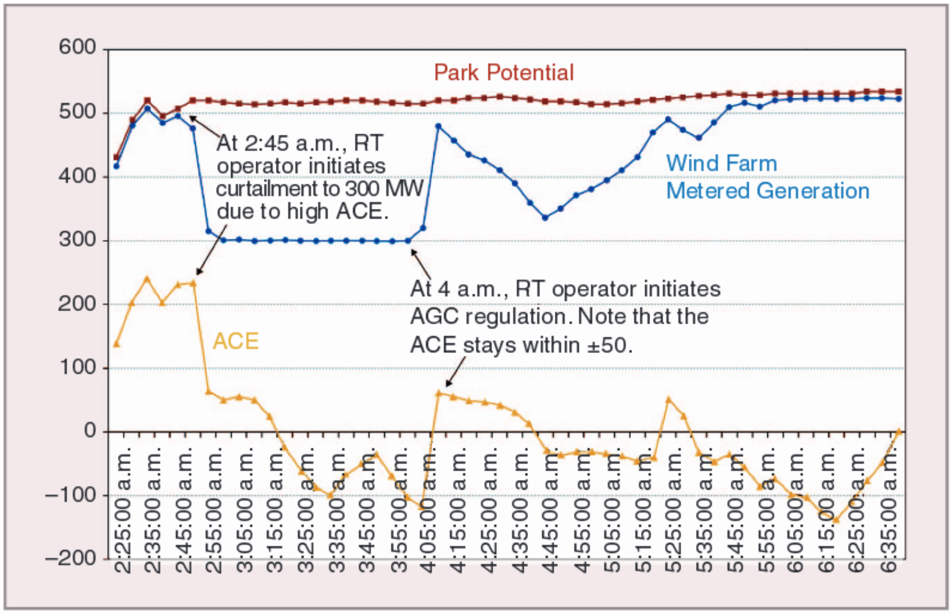
Regarding inertia and system stability, analysis by WECC in 2013 found that in a scenario with very high renewable penetration across the West, "the system results did not identify any adverse impacts due to the lower system inertia or differently stressed paths due to the higher penetration of variable generation resources." Analysis conducted for the California grid operator identified no major concerns for frequency response in a transition to a high renewable future, finding that "[n]one of the credible conditions examined, even cases with significantly high levels of wind and solar generation (up to 50% penetration in California), resulted in under-frequency load shedding (ULFS) or other stability problems."[90] Adding wind generation can increase total power system frequency response by causing conventional power plants to have their output reduced, which provides them with more range to increase their output and provide frequency response.[91]

**Balancing the power system with wind and solar**

New techniques employing wind and solar plants' sophisticated controls and power electronics enable renewable plants themselves to provide fast-acting frequency regulation. NREL and the California grid operator recently examined how solar plants can provide dispatchability and other reliability services.[92] Another NREL report found that "wind power can act in an equal or superior manner to conventional generation when providing active power control, supporting the system frequency response and improving reliability."[93] There is the opportunity cost of lost production from using wind and solar plants in this way, though in some hours it can be the most cost-effective source of flexibility on the power system.

NREL's report documented how major utilities like Xcel Energy are using this capability of wind plants in some hours to provide some or all of the frequency response and regulation needed to maintain power system reliability, which has enabled Xcel's Colorado power system to at times reliably obtain more than 60 percent of its electricity from wind energy. The following chart shows that the total imbalance of electricity supply and demand, or Area Control Error (ACE), is tightly controlled when wind plants provide frequency regulation on Xcel's power system.[94]

[89] https://www.rtoinsider.com/pjm-utility-dc-area-outage-14217/
[90] Available at http://www.caiso.com/Documents/Report-FrequencyResponseStudy.pdf
[91] http://web.mit.edu/windenergy/windweek/Presentations/GE%20Impact%20of%20Frequency%20Responsive%20Wind%20Plant%20Controls%20Pres%20and%20Paper.pdf
[92] https://www.caiso.com/Documents/UsingRenewablesToOperateLow-CarbonGrid.pdf
[93] Available at http://www.nrel.gov/docs/fy14osti/60574.pdf
[94] http://iiesi.org/assets/pdfs/ieee-power-energy-mag-2015.pdf




NREL also performed studies[95] on frequency response in the Eastern and Western Interconnections for scenarios with high wind energy penetration, which found adding wind generation is unlikely to significantly reduce frequency response and can actually improve it.

It should also be noted that many conventional generators currently provide little to no frequency response. NERC has explained that a failure of conventional generators to provide frequency response is the primary cause of observed declines in system-wide frequency response, while NERC explicitly notes that the growth of wind and solar is not responsible for the decline.[96] This is important to note because some have attempted to claim that conventional resources inherently provide essential reliability services while renewable resources have little to no ability to provide these services. As explained above, both claims are incorrect. Not only are there many counterexamples, but in many cases renewable resources actually exceed conventional resources in their ability to provide and in their provision of essential reliability services.

It is also important to remember why the power system needs frequency response and ride-through services in the first place. The ability to ride-through voltage and frequency disturbances is needed in large part because large conventional power plants cause frequency and voltage excursions when they unexpectedly fail, though transmission line failures can also cause these disturbances. Frequency response is also primarily needed so that the grid can reliably accommodate the unexpected failure of large conventional power plants. Because large conventional power plant failures occur so abruptly, often in a fraction of a second, the response from other power plants must also occur very quickly.

Because different resources face drastically different costs for providing services like frequency response, a market is by far the most efficient solution for procuring these services.  This is particularly true because, as discussed in the NERC document cited above, many conventional generators can provide frequency response at low cost but have opted not to because there is no financial incentive to do so.  In contrast, requiring the provision of this and other services from all generators, such as through a blanket

[95] Available at: http://www.nrel.gov/docs/fy13osti/58077.pdf, http://www.nrel.gov/docs/fy15osti/62906.pdf
[96] http://www.nerc.com/files/FinalFile_Comments_Resp_to_Sept_Freq_Resp_Tech_Conf.pdf

requirement written into interconnection standards, would unnecessarily impose major costs by requiring resources that cannot cost-effectively provide these services to do so.

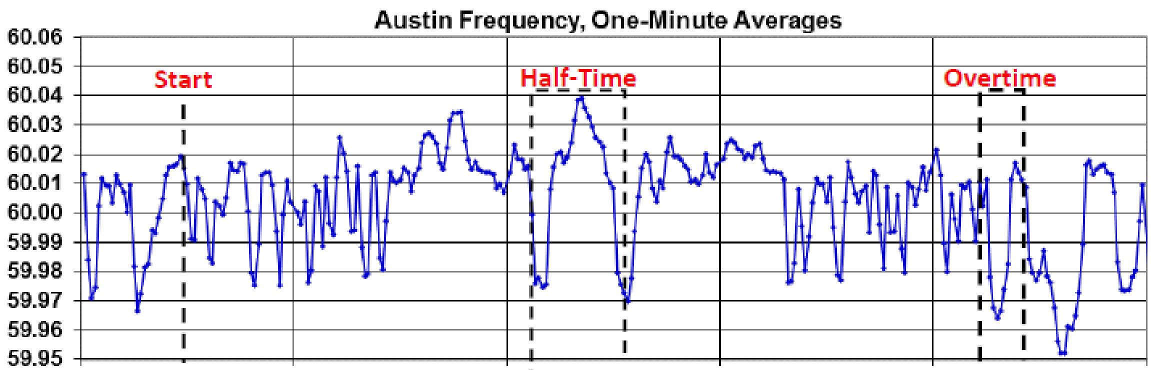
Markets would also appropriately incentivize resources that can cost-effectively provide these services to do so.  For example, technology that allows wind turbines to provide inertial response is commercially available, but purchasers are not asking for them because there is no financial incentive for providing these services. Similarly, while under most conditions it may not be cost-effective for wind generators to provide frequency regulation and response, markets send the appropriate price signal and ensure that the least-cost resources are selected to provide these services.

# 7. What about the variability of renewable energy?

**Variability and uncertainty are nothing new for grid operators, as they have always dealt with large and unexpected fluctuations in electricity supply and demand.** Since the days of Thomas Edison, grid operators have had to constantly accommodate variability in electricity demand and supply by increasing and decreasing the output of flexible generators – power plants like hydroelectric dams or natural gas plants that can change their level of generation. Thus, the water kept behind a dam or the natural gas held in a pipeline may be thought of as a form of energy storage, with operators using this energy when it is needed and "storing" it when it is not. For a video illustrating the balancing act of electricity supply and demand, see: https://www.youtube.com/watch?v=gSiCRZcJnfE.

**Grid variability and uncertainty**

Electricity demand fluctuates unpredictably in response to factory equipment coming on and offline, residential users turning electric appliances on, and changes in weather as people turn on air conditioners and heaters. The chart below illustrates how power system frequency in Texas fluctuated during the 2017 Super Bowl, with declines in frequency occurring during breaks in the game, presumably because demand spiked as people used appliances.[97]




Grid operators have always kept large quantities of fast-acting generation in reserve to respond to fluctuations in demand as well as the instantaneous and unpredictable failures of large conventional power plants, a challenge and cost that is far greater than accommodating any incremental variability added by the gradual and predictable changes in the aggregate output of renewable energy. Grid operators use these same flexible resources to accommodate any incremental variability introduced by renewable energy that is not canceled out by other changes in electricity supply or demand.

Over the last century, grid operators moved to larger interstate power systems so that changes like an increase in electricity demand caused by a factory coming online would be offset by decreases in electricity demand occurring elsewhere, or an unexpected outage at a power plant could be compensated for by a power plant several states away. The grid remains reliable even though it takes power from many sources that vary over time, just like the Mississippi River takes water from many varying tributaries yet keeps a steady flow into the Gulf of Mexico.

This diversity benefit provides even greater value for wind energy because a region's wind plants are experiencing different weather at any one point in time. Just as a customer in Washington DC turning on their air conditioner is canceled out by a customer in Chicago turning theirs off, output changes at one

[97] Email, M. Grady, University of Texas at Austin

wind plant are often offset by an opposite change at another wind plant. Furthermore, most output changes for the total wind fleet are canceled out by other changes in electricity supply and demand, mostly by random fluctuations in electricity demand.

Because wind turbines are spread across a large area, it typically takes many hours for a weather event to affect a large share of a region's wind output. Changes in total wind energy output occur very slowly, even though the winds may change fairly rapidly at any one location. The diversity of wind energy output can be seen in this real-time map of wind speeds: http://hint.fm/wind/. NREL's Renewable Energy Futures study, which examined a future in which nearly 50% of electricity is reliably provided by wind and solar, also shows the value of this diversity. For a sample of the study's modeling of hourly electricity supply at nearly 50% wind and solar energy, see: https://www.youtube.com/watch?v=fQl7PS243Dg NREL has recently completed more detailed analysis examining high wind and solar penetrations in the Eastern U.S.; videos of their work are available here: https://www.nrel.gov/grid/ergis.html

A key part of the solution is that weather forecasting makes changes in wind energy output predictable, unlike the abrupt outages at conventional power plants that can take 1,000 MW or more offline instantaneously. Wind energy forecasting greatly reduces uncertainty about what wind energy output will be over the next day or more. The use of weather forecasting to reduce uncertainty is also nothing new for grid operators, as grid operators already use weather forecasting to predict how electricity demand will be driven by consumers running their air conditioners or heaters.

Thus, contrary to most people's intuitive experience that winds are highly variable and electricity demand and supply is fairly stable, the opposite is actually true at the grid operator level. Data from the PJM independent grid operator illustrate this fact. The largest hourly changes in electricity demand are typically about 10 times larger than the largest hourly changes in wind energy output, even though PJM has over 7,000 MW of wind energy on its system.[98]

A tremendous amount of flexibility has been built into the power system to accommodate these large and abrupt swings in electricity supply and demand. Demand for electricity can vary by a factor of three or more depending on the time of day and year, which nationwide translates into hundreds of gigawatts of flexibility that are already built into the power system. Because of this existing flexibility, there is almost never a need to build new power plants to accommodate any incremental increase in variability caused by adding renewable energy. Any increase in the need for operating reserves is met by simply making greater use of existing flexible resources.

Grid operators accommodate variability using different types of "operating reserves," which are provided by flexible resources. As described in more detail under Question 8 below, "regulating reserves" are the fast-acting reserves for accommodating moment-to-moment variability in electricity supply and demand. Grid operators also use fast-acting "contingency reserves" to accommodate unexpected and abrupt failures of large conventional generators. These fast-acting reserves are typically provided by operating power plants changing their level of output.

Slower-acting reserves can be provided by a much larger group of resources, often including power plants that are offline but can start up on short notice. These "non-spinning" reserves typically cost far less than the fast-acting reserves provided by operating power plants. This is important because it means that the gradual and predictable changes in wind output are much less costly to accommodate than the

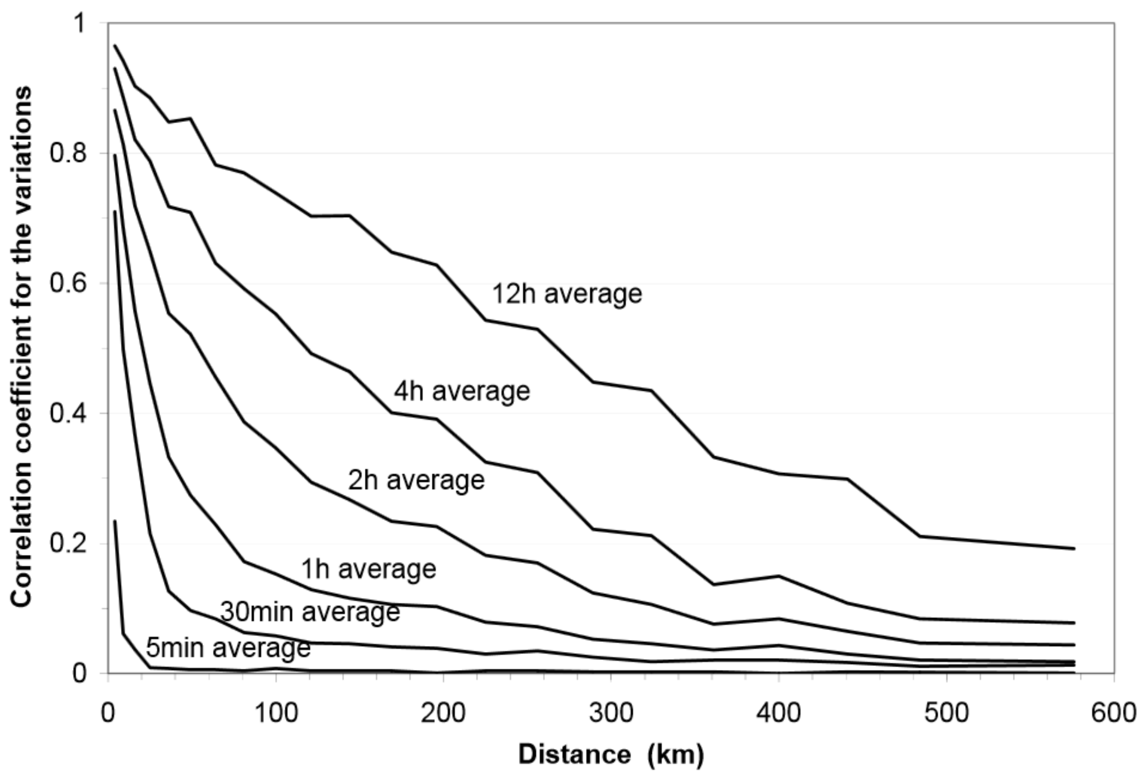
[98] http://www.pjm.com/markets-and-operations/ops-analysis.aspx, http://www.pjm.com/markets-and-operations/energy/real-time/loadhryr.aspx

instantaneous and unpredictable outages that occur at large conventional power plants, which require grid operators to hold expensive fast-acting reserves 24/7/365.

**Wind variability and uncertainty**

Several charts derived from wind integration studies and actual grid operating experience help illustrate the variability and uncertainty of wind energy and how they interact with other sources of variability and uncertainty. The first chart shows that as the distance between two wind plants increases, it becomes more likely that their output is not changing in the same direction.[99] This makes sense, because few weather systems are large enough and aligned in such a way that they could affect more than a small number of wind plants simultaneously. As a result, it becomes likely that changes in their output will offset each other. Importantly, the chart shows that for the 5-minute timeframe covered by the fast-acting and most expensive regulating reserves, even a dozen or so miles between two wind plants is enough to make it likely that changes in one wind plant's output will cancel out changes in the other plant's output. This offsetting impact, combined with the fact that electricity demand contributes far more total variability at the 5-minute timescale than wind, explains why wind generation only minimally contributes to the need for fast-acting regulating reserves.

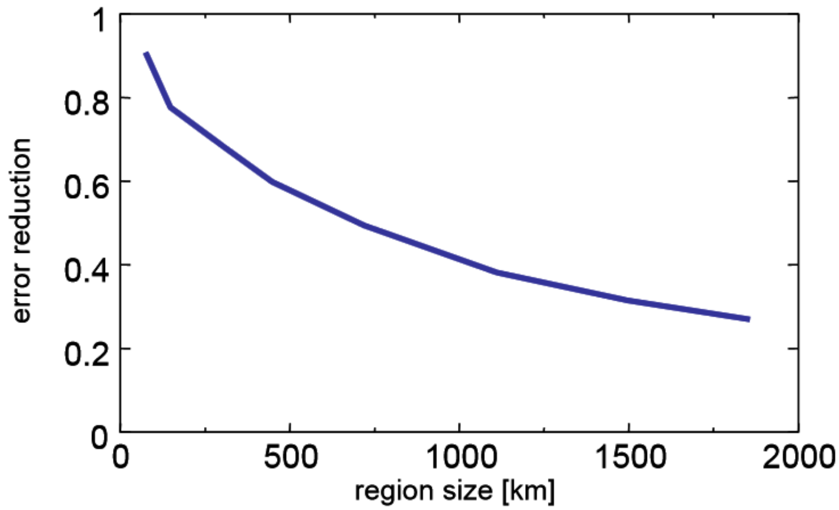
**Because wind plant output changes are not correlated across large areas, these output changes cancel each other out**




[99] https://www.ieawind.org/annex_XXV/PDF/Final%20Report%20Task%2025%202008/T2493.pdf, page 25

For similar reasons, wind and solar forecast errors also tend to cancel out over larger areas, as shown below. This allows grid operators to more accurately predict changes in wind output and accommodate them at low cost.[100]

**Wind forecast error decreases over larger geographic areas**



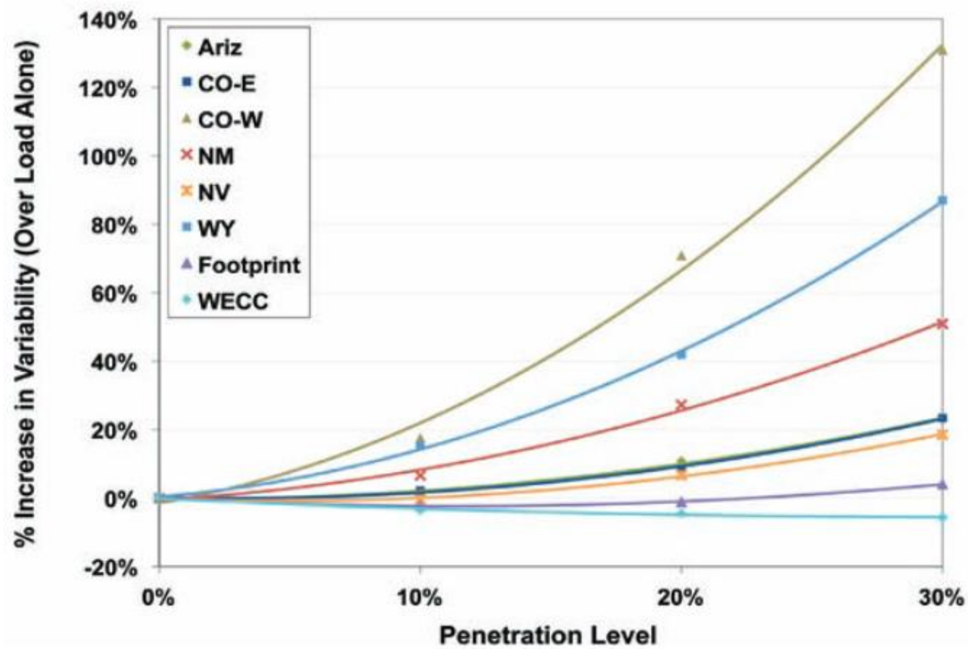

Because increases in output at one wind plant tend to cancel out decreases in output at others, total wind variability grows more slowly as one adds more wind. Said another way, adding more wind generation increases total wind variability, but tends to reduce the amount of wind variability per MW of installed wind capacity.

The following chart shows how total system hourly variability changes at higher levels of renewable use. For smaller geographic areas, total system variability grows significantly as renewable variability eclipses electricity demand variability. However, over a geographic area the size of the entire Western U.S., renewable variability cancels out other renewable variability and demand variability to such a large extent that total power system variability actually decreases as one increases to 30% renewable energy use.[101] This geographic diversity drives the benefits associated with coordinating grid operations across larger areas, as discussed in more detail in Chapter 10.

[100] *Ibid.*, pages 26-28

[101] Pages 83-84 at http://www.nrel.gov/docs/fy10osti/47434.pdf. "WECC-wide, the variability at 30% penetration is actually *less* than the variability with load alone." [emphasis in original] "The fact that the net load variability at the footprint and WECC level does not significantly increase with penetration speaks volumes about the impact of temporal averaging, geographic diversity and wide-area aggregation on variability."

**Change in total power system variability**
**based on renewable use level and size of geographic area**




Dozens of grid operator studies and years of real-world operating experience confirm that wind energy only slightly adds to total power system variability, and that most changes in wind energy output are canceled out by opposite changes in electricity supply and demand.[102] Because demand is a far larger contributor to total fast variability, changes in wind output on the minute-to-minute are typically canceled out and have minimal impact on total system fast variability.

Variability in wind and solar does not need to be managed on a stand-alone basis. Rather, the grid operator is only concerned about managing the combined variability of all sources of supply and demand. This greatly reduces the cost and challenge of accommodating variability, as the total variability is less than the sum of its parts. As an analogy, it would be highly inefficient and counterproductive to have a battery or power plant accommodating changes in the electricity demand at your house as you turn appliances on and off, as nearly all of those changes are canceled out by other changes on the aggregate grid, whether caused by your neighbor or someone 500 miles away turning their TV off as you turn yours on.

The table below shows that the regulating reserve need for wind is much smaller than the contingency reserve need for conventional generation. The results are consistent, and surprising. For example, the ERCOT (Texas) and MISO (Upper Midwest) grid operators each reliably accommodate more than 10,000 MW of wind energy on their power systems. These significant levels of wind penetration are being accomplished with limited amount of reserves, with ERCOT finding that amount of wind is reliably accommodated with less than 50 MW of additional fast-acting reserves.[103] ERCOT has also noted that it has been able to integrate renewable energy with a "minimal increase" in operating reserves.[104] Similarly,

[102] https://www.uvig.org/resources/
[103] http://www.wspp.org/filestorage/panel_1_maggio_ercot
[104] http://www.ercot.com/content/committees/other/fast/keydocs/2014/ERCOT_AS_Concept_Paper_Version_1.1_as_of_11-01-13_1445_black.doc , page 8

MISO explains that the incremental need for fast-acting reserves due to wind is "little to none."[105] The grid operator for the Great Lakes and Mid-Atlantic states, PJM, holds 1,375 MW of expensive, fast-acting reserves 24/7 in case a large fossil or nuclear power plant unexpectedly breaks down. For comparison, PJM's renewable integration study found that adding more than 28,000 MW of wind only increases the need for these fast-acting reserves by around 360 MW.[106]

The table below focuses on the two fast-acting types of reserves described above, as they are the most expensive types of operating reserves. These two types are also the focus because all grid operators hold regulation and contingency reserves, while the definitions and use of slower-acting reserves vary considerably from grid operator to grid operator, with some not holding these reserves at all but relying on the energy market to provide the needed flexibility.[107] Wind's variability does increase the need for other types of slower-acting, non-spinning reserves, though these reserves are typically much less expensive than regulating reserves. In the next section, a more detailed look at the ERCOT data expands the analysis to include those other types of reserves, and demonstrates that wind's total operating reserve needs are far less costly than the reserve needs for conventional generation.

| Grid operator | Fast Contingency[108] Reserves (MW) | Renewable Fast Reserves (MW)[109] |
|---|---:|---:|
| CAISO | 850 | <230 |
| ERCOT | 2,800 | 53 |
| MISO | 1,000 | "little to none" |
| PJM | 1,375 | 18[110] |
| ISO-NE | 1,750 | 20[111] |
| NYISO | 1,310 | 36 |
| SPP | 545 | 216[112] |

Adding wind energy does affect the operation of other power plants aside from the impact on operating reserve needs. However, the introduction of any new generating resource, particularly a low-marginal cost

[105] https://www.ferc.gov/CalendarFiles/20140411130433-T1-A%20-%20Navid.pdf
[106] http://www.pjm.com/~/media/committees-groups/committees/mic/20140303/20140303-pjm-pris-final-project-review.ashx, page 111
[107] http://www.consultkirby.com/files/NREL-TP-5500-51978_Operating_Reserves_and_Variable_Generation.pdf, page 18
[108] https://www.energy.gov/sites/prod/files/2017/01/f34/Maintaining%20Reliability%20in%20the%20Modern%20Power%20System.pdf, page 23
[109] *Ibid.,* page 25, except where noted
[110] http://www.pjm.com/~/media/committees-groups/subcommittees/irs/postings/pjm-pris-task-3a-part-b-statistical-analysis-and-reserves.ashx, page 97
[111] https://www.iso-ne.com/static-assets/documents/committees/comm_wkgrps/prtcpnts_comm/pac/reports/2010/newis_report.pdf, page 21
[112] https://www.spp.org/documents/34200/2016%20wind%20integration%20study%20(wis)%20final.pdf page 96, using 95th percentile requirement for 20-minute variability

resource like wind energy, similarly affects the operations of other resources. Moreover, much of this impact is the intentional benefit that wind generation should displace more expensive and polluting forms of energy, and it is difficult if not impossible to disentangle that impact from wind's other impacts on those generators.[113] A further complicating factor is that each grid operator uses different methods for accommodating slower sources of variability and uncertainty, with some using the energy market to provide the flexibility and others using reserve products. As a result, this paper does not attempt to address those issues beyond what has already been discussed by others.[114]

Returning to the operating reserve table above, a powerful yet under-appreciated mathematical principle explains why wind variability contributes little to total power system variability. Two sources of uncorrelated variability cancel each other out such that the total variability is much less than the sum of the parts. Fortuitously, wind variability and electricity demand variability are uncorrelated at sub-hourly timescales. Mathematically, total variability is the square root of the sum of the squares of the individual variabilities, or sqrt($x^2$+$y^2$). As an example, if the variability of electricity demand is 10 MW and the variability of wind generation is 5 MW, the total variability is not 15 MW, but rather sqrt(100+25) = 11.18 MW. So in this example, adding 5 MW of wind variability only increased total system variability by 1.18 MW, with the other roughly 4 MW of variability canceled out by counteracting demand variability.

The efficiency with which grid operators manage wind variability by aggregating it with all other sources of variability was concisely summed up by an analyst for the International Energy Agency:
"Variability is not just some new phenomenon in grid management. What we found is that renewable energy is not fundamentally different. The criticisms of renewables often neglect the complementarities between different technologies and the way they can balance each other out if spread over certain regions and energy types.

"Grid operators are constantly working to balance available supply with demand – it's what they do. There are always natural variations that cause spikes in demand, reductions in supply or create disturbances in frequency and voltage. Once you see there are a variety of ways to properly manage that variability, you start whittling away at the argument that you always need storage or a megawatt of natural gas backup for every megawatt of renewable energy."[115]

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[113] http://www.nrel.gov/docs/fy11osti/51860.pdf, pages 6-11
[114] *Id.*
[115] http://thinkprogress.org/climate/2011/06/15/245880/top-5-coolest-ways-companies-are-integrating-renewable-energy-into-the-grid/

# 8. How much does it cost to integrate wind?

**While it is true that wind energy's variability does slightly increase the need for the operating reserves that grid operators use to keep supply and demand in balance, all forms of energy impose integration costs on the power system.[116] In regions with efficient grid operating procedures, by a large margin the most expensive challenge for grid operators is accommodating the abrupt failures of large conventional power plants, not the gradual and predictable changes in wind energy output.**

For example, Texas grid operator data show that the operating reserve costs for conventional power plants are far larger than the operating reserve costs for wind generation, even though Texas has more wind energy than any other state and one of the highest levels of wind generation for a U.S. grid operator. The Texas grid operator ERCOT holds[117] 2,800 MW of fast-acting reserves 24/7/365 to keep the lights on in case one of the state's large fossil or nuclear power plants experiences an unexpected failure, as all power plants do from time to time. This large amount of contingency reserves is typical for other power systems as well.[118] In contrast, the reserve need for wind is far smaller and can be met with less expensive, slower=acting reserves. The following table compares the reserve costs for wind versus other sources of variability on the ERCOT grid.

| Factor | Total annual reserve cost (million $) | % of total reserve cost | Cost per electric bill | Cost per MWh of total/wind generation |
|---|---|---|---|---|
| **Conventional power plant failures** | **$239.690** | **67%** | **76 cents** | **$0.65/MWh** |
| **Conventional and demand deviations** | **$103.359** | **29%** | **33 cents** | **$0.28/MWh** |
| **Wind** | **$13.740** | **4%** | **4 cents** | **$0.37/MWh** |

As the table shows, the cost of additional reserves to accommodate wind accounts for about 4 cents out of a typical Texas household's $136 monthly electric bill[119], or 1/35,000th of a typical electric bill. In contrast, the $240 million annual cost of reserves to accommodate conventional power plant failures works out to about 76 cents per monthly electric bill. In other words, the total cost of contingency reserves for conventional power plant failures is more than 17 times larger than the cost of all wind-related reserves.

On a per-MWh of energy produced basis, wind's reserve cost is still about half as large as conventional power plants' reserve costs (1 MWh is roughly the amount consumed by a typical household in a month). Wind's reserve cost is about $0.37/MWh of wind when allocated across the wind MWh generated in ERCOT last year, which equates to roughly 1% of the typical price for 1 MWh of wholesale electricity. In contrast, the cost of contingency reserves was $.65/MWh when allocated across all MWh generated in ERCOT last year, and even higher if only allocated to generation from the larger conventional power plants that cause the need for contingency reserves.[120]

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116 http://www.nrel.gov/docs/fy11osti/51860.pdf, pages 11-16.
117 http://www.ercot.com/content/news/presentations/2012/Dumas_IPPSA_March13.pdf, page 5
118 http://www.consultkirby.com/files/Tm2003-152_Allocate_Res_Reg_Cost.pdf
119 Available at: http://www.eia.gov/electricity/sales_revenue_price/pdf/table5_a.pdf
120 For more background on these calculations, see http://aweablog.org/blog/post/fact-check-winds-integration-costs-are-lower-than-those-for-other-energy-sources

The table above is directly calculated from the following ERCOT data. The first three rows in the following table list ERCOT data[121] on the incremental amount of reserves it holds to accommodate various sources of variability, while the fourth row lists the average cost of those reserves in 2013, also calculated from ERCOT data.[122] The last three rows use this data to calculate the total reserve cost for each source of variability.

| | Regulation down (fast-acting reduction in electric supply) | Regulation up (fast-acting increase in electric supply) | Responsive reserves (contingency reserves) | Non-spinning reserves (slower-acting reserves) |
|---|---|---|---|---|
| Contingency reserves for conventional power plant failures (MW) | | | 2,800 | |
| Incremental reserves for wind (MW) | 14 | 42 | | 328 |
| Electricity demand variability and deviations at conventional power plants (MW) | 476 | 508 | | 1,474 |
| **Average cost of reserve ($/MW)** | **$4.89** | **$8.57** | **$9.77** | **$3.47** |
| Annual reserve cost for conventional power plant failures (million $) | | | $239.690 | |
| Annual reserve cost for wind (million $) | $0.585 | $3.159 | | $9.996 |
| Annual reserve cost for electricity demand variability and supply deviations at conventional power plants (million $) | $20.372 | $38.126 | | $44.860 |

The 2- to 3-fold cost premium for faster-acting regulation and responsive reserves versus slower-acting non-spinning reserves is an important driver of the difference in total cost for wind versus conventional. Slower-acting reserves can be provided by a much larger pool of resources, often including power plants that are offline but can start up on short notice. These "non-spinning" reserves typically incur far less cost to provide operating reserves than operating power plants, as reflected in the reserve prices shown in the table above. In other regions the cost difference can be even more pronounced, with fast-acting reserves sometimes dozens of times more expensive than slower-acting reserves.[123]

Moreover, recent analysis by NREL indicates that higher levels of renewable energy may actually decrease the total cost of operating reserves, even though the quantity of operating reserves has increased. Adding renewable generation displaces the output of the most expensive power plants that are currently

[121] Available at: http://www.wspp.org/filestorage/panel_1_maggio_ercot
[122] Data available at http://mis.ercot.com/misapp/GetReports.do?reportTypeId=13091&reportTitle=Historical%20DAM%20Clearing%20Prices%20for%20Capacity&showHTMLView=&mimicKey
[123] http://www.consultkirby.com/files/Ancillary_Services_-_Technical_And_Commercial_Insights_EXT_.pdf, page 30

operating, freeing those generators up to provide reserves and therefore driving down the cost of reserves.[124] As a result, in NREL's analysis of the Colorado and Wyoming power system, total operating reserve costs actually fell from $32.3 million at a 25% renewable penetration to $31.2 million at a 35% renewable penetration, even though the quantity of operating reserves increased.

It is also important to keep in mind that all operating reserve costs are a very small component of the total costs reflected in the average ratepayer's electric bill. For example, total regulation reserve costs account for 0.2% of total PJM wholesale market costs, or about $0.11/MWh.[125] PJM's renewable integration study found that the current amount of renewable generation on its power system increased the need for regulation reserves from 1,204 MW to 1,222 MW.[126] Thus, the incremental regulation reserves needed due to renewable energy accounted for less than 1.5% of 0.2% of total wholesale market costs, or about 2 cents per year for a household that consumes 1 MWh per month. While this calculation does not include slower-acting and less expensive types of operating reserves, it still indicates the very small magnitude of wind-related reserve costs. MISO data show an even lower total cost for operating reserves than PJM.[127]

In short, wind-related reserve costs are a small subset of a small subset of the average ratepayer's electric bill. It is not surprising that the total wind reserve cost was calculated at 4 cents per month for the average Texas customer, even with more than 10,000 MW of wind generation on the main Texas power system.

As addressed later in the answer to Question 10, renewable integration costs may appear to be higher in parts of the country with less efficient grid operating practices, particularly in the Western U.S. However, because these costs would likely be reduced to the levels described above if efficient operating practices were in place, those higher costs should be attributed to the obsolete operating practices that are in place, not renewable generation.

Finally, it should be noted that integration costs for conventional power plants are not assigned to conventional power plant owners, but are rather paid by electricity customers. Wind farm owners can be and are charged for integration costs, while the integration costs for conventional power plants are socialized across consumers' electric bills. As a result, false claims that renewable integration costs will impose a significant burden on customers add insult to injury because conventional generators' far larger integration costs are the ones that are always paid by ratepayers.

**Impact of low-cost generation on other generators**

Some have also argued that adding low-cost wind energy to the power system can affect the way in which other power plants are operated. However, it is important to keep in mind that adding any type of low-marginal-cost generation, whether from coal, nuclear, hydro, or other renewable resources, will affect how more expensive power plants are operated. This is the normal and efficient outcome of electricity markets using the least-cost resources first. As NREL has noted, "Baseload plants can also increase the costs of operating other generators. … adding a nuclear plant (or any lower cost baseload generation) forces coal to cycle and also displaces both the combined cycle and combustion turbine-based generation."[128]

[124] http://www.nrel.gov/docs/fy13osti/58491.pdf, page 31
[125] http://www.monitoringanalytics.com/reports/PJM_State_of_the_Market/2016/2016-som-pjm-volume1.pdf, page 16
[126] PJM study results, slide 111, available at: http://www.pjm.com/~/media/committees-groups/subcommittees/irs/postings/pjm-pris-final-project-review.ashx
[127] https://www.misoenergy.org/Library/Repository/Report/IMM/2015%20State%20of%20the%20Market%20Report.pdf
[128] http://www.nrel.gov/docs/fy11osti/51860.pdf, page 13

# 9. Don't grid operators need to add backup to integrate wind?

No. One of main reasons grid operators built an integrated power system is so that all power plants can back up all other power plants. As explained under Questions 4 and 7 above, the variability and uncertainty that affect all sources of electricity supply and demand are largely canceled out by other sources of variability and uncertainty. As a result, having a dedicated backup source for each source of variability would be highly inefficient and counterproductive, as counteracting that resource's variability would often increase total power system variability. As an analogy, it would be highly inefficient and counterproductive to have a dedicated resource at your house accommodating all fluctuations in your electricity demand, such as a battery or small dispatchable power plant, as nearly all of those changes are canceled out anyway by other changes on the aggregate grid.[129] Unfortunately, as NREL has noted,[130] the misconception that renewable resources must be paired with dispatchable resources has been used as the flawed assumption for many studies.[131]

Moreover, any total power system variability and uncertainty is most efficiently accommodated by the large pool of flexible resources available on the power system. Like any generation resource, wind works best as part of a mix of other resources on the power system. As explained above, a major challenge and expense faced by grid operators is how to keep the lights on when individual power plants break down, as all power plants do from time to time. The challenge is particularly great for failures at large fossil and nuclear power plants, which because of their size can take offline in a fraction of a second enough electricity to supply a large city.

Over the last century, power grid operators have perfected tools for combining hundreds of power plants that are each individually unreliable into a power system that is very reliable. By using most power plants to "back up" all other power plants, grid operators ensure that the lights stay on when even the largest power plant on the grid breaks down. This process works so well that most people are not aware that it occurs, even though the expense of maintaining that backup 24/7 for the unpredictable failure of conventional power plants is quite large, as explained under the answer to Question 8 above.

Grid operators typically make a distinction between operating reserves, which were addressed in this answer and the preceding answer, and "planning reserves," which were discussed in more detail in Chapter 4. The primary distinction is that grid operators think about planning reserves on a years-ahead basis when they are deciding what power plants to build, while they think about operating reserves on a day-ahead to real-time basis when they are deciding what power plants to operate. Planning reserves are essentially the cushion of extra power plant capacity that grid operators build so that they will have enough power plants even if some of those power plants are not available on a particular day. For both operating reserves and planning reserves, the answer is that wind can be reliably added at low cost, as the power plant capacity and flexibility that is needed already exists on the power system.

[129] Discussion of pairing dedicated storage or a dedicated "backup" power plant with a particular resource, or combining several resources to create a virtual power plant or a microgrid, often falls into this trap. The power system was built to realize the diversity benefits of having all resources backed up by all other resources and all sources of variability canceling each other out, so dis-aggregating the grid would be a step backwards.

[130] http://www.nrel.gov/docs/fy11osti/51860.pdf, page 27

[131] Examples of studies that are flawed because they have relied on this incorrect pairing assumption include http://pubs.acs.org/doi/full/10.1021/es801437t and http://instituteforenergyresearch.org/wp-content/uploads/2016/07/IER_LCOE_2016-2.pdf; That claim was debunked here http://www.aweablog.org/koch-groups-try-debunked-wind-attack-for-a-fourth-time/.

# 10. What can help accommodate higher levels of wind?

Grid operating reforms and transmission upgrades are by far the lowest hanging fruit for making the power system more flexible and efficient. Bulk power system grid operating reforms and transmission upgrades that facilitate the integration of renewable energy also provide major net benefits to consumers and improve reliability even in the absence of wind energy, so they can be implemented at negative cost.

Transmission expansion is a key solution for reliably and cost-effectively integrating large amounts of renewable energy. SPP,[132] MISO,[133] and other grid operators have released studies showing that transmission more than pays for itself by providing consumers with access to lower cost electricity and improving the efficiency and competitiveness of power markets by allowing inter-regional trade. Transmission facilitates the integration of renewables by providing access to the best renewable sites as well as allowing power to be moved from region to region in response to fluctuations in electricity supply and demand. Modeling analysis in the journal Nature Climate Change demonstrated that a major benefit of transmission is capturing the geographic diversity in wind and solar output due to the fact that "the average variability of weather decreases as size increases; if wind or solar power are not available in a small area, they are more likely to be available somewhere in a larger area." As a result, the study notes "paradoxically, the variability of the weather can provide the answer to its perceived problems."[134]

Turning to grid operating reforms, reports by NREL[135] and the Western Governors Association[136] provide an overview of that can cost-effectively improve power system flexibility and efficiency, including:

- Better coordinating regional grid operations, such as through RTOs/ISOs or shared markets like an Energy Imbalance Market[137] (EIM)
- Consolidation or better coordination among grid operators
- Faster generation scheduling and dispatch intervals
- Better integrating wind energy forecasting into grid operations
- Establishment of ancillary services markets that incentivize flexible resources such as demand response and flexible generation

One of the most beneficial solutions is an Energy Imbalance Market, or EIM. An Energy Imbalance Market is a voluntary market that allows utilities and other grid operators to "net out" changes in electricity supply and demand with their neighbors. This is typically much more cost-effective than each individual grid operating managing all variability on its own without regard for what its neighbors are doing.

For example, under current operating practices in much of the Western U.S., one utility may be ramping up its gas power plants to accommodate an unexpected increase in electricity demand, while a neighboring utility is ramping its gas power plants down to accommodate an increase in wind generation. A far more efficient solution would be for the utilities to allow the increasing wind generation to meet the increasing electricity demand and not change the output of their gas power plants. As described above, this diversity benefit is one of the fundamental reasons why large interstate power systems were built in the first place.

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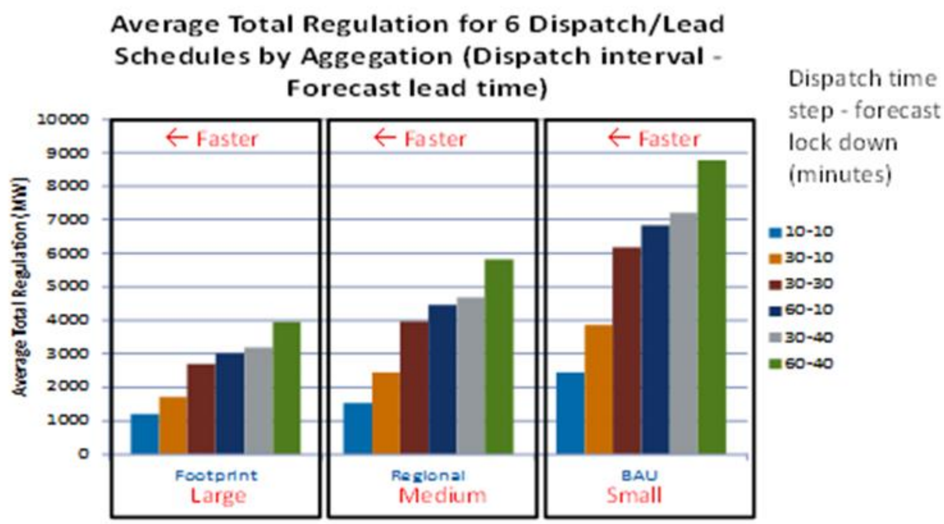
[132] http://www.spp.org/documents/35297/the%20value%20of%20transmission%20report.pdf
[133] https://www.misoenergy.org/Library/Repository/Study/Candidate%20MVP%20Analysis/MTEP14%20MVP%20Triennial%20Review%20Report.pdf
[134] http://www.nature.com/nclimate/journal/vaop/ncurrent/full/nclimate2921.html
[135] Available at: http://www.nrel.gov/docs/fy09osti/46273.pdf, http://www.nrel.gov/docs/fy13osti/60451.pdf
[136] Available at: http://www.westgov.org/component/docman/doc_download/1610-meeting-renewable-energy-targets-in-the-west-at-least-cost-the-integration-challenge-full-report?Itemid
[137] https://www.caiso.com/Documents/EnergyImbalanceMarketFAQs.pdf

An EIM also reduces another major inefficiency in current power system operations in the Western U.S. Currently, most power plants are told to produce at a constant level of output for an hour, which requires the use of expensive operating reserves to accommodate intra-hour changes in electricity supply and demand. In much of the rest of the U.S., grid operators allow generators to change their output levels at intervals of 5 minutes and with lead times of 10 minutes or less, rather than hourly. This allows generators to use their inherent flexibility to respond to changes in electricity supply and demand based on the incentives provided in the energy market. Instead of holding enough expensive operating reserves to handle the worst case of supply and demand variability that could occur over the course of that hour, this variability is accommodated at virtually no cost through the energy market. An additional benefit is that the less than 10 minute lead time for updating generator output levels allows for a far more accurate forecast of electricity demand and supply than is possible an hour or more ahead.

As shown in the chart below, coordinating grid operations over a larger area and allowing faster and more frequent updates to generation dispatch greatly reduces the need for operating reserves.




Milligan, Kirby, King, Beuning (2011), The Impact of Alternative Dispatch Intervals on Operating Reserve Requirements for Variable Generation. Presented at 10th International Workshop on Large-Scale Integration of Wind (and Solar) Power into Power Systems, Aarhus, Denmark. October

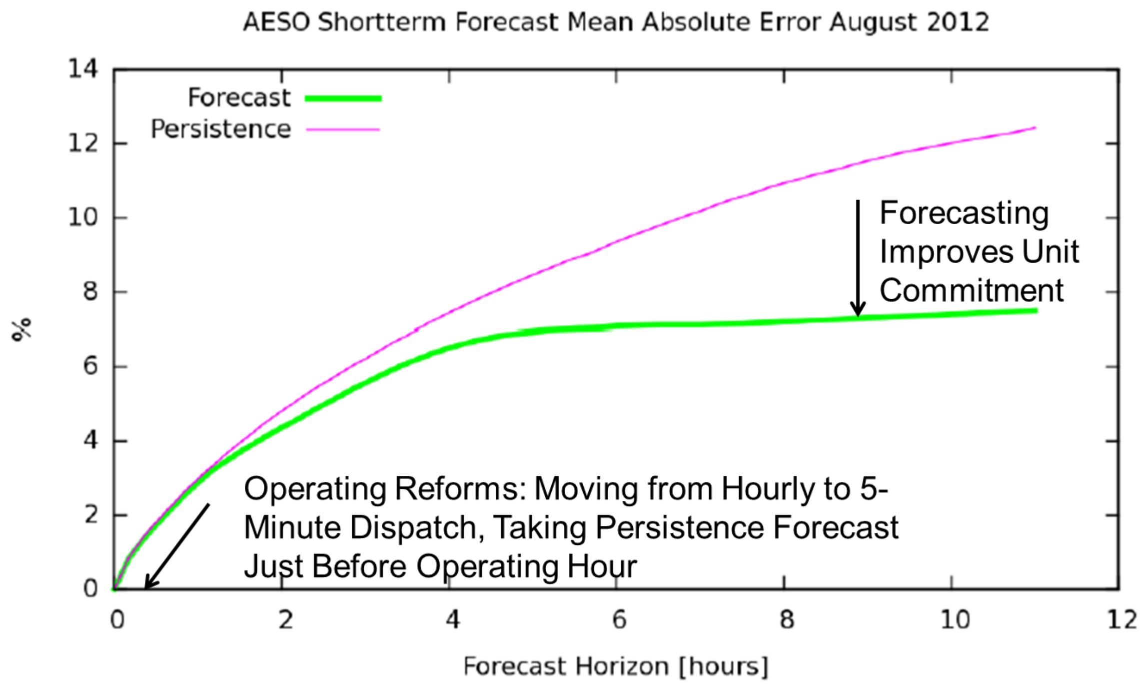
Many studies have documented the sizeable net benefits of grid operating reforms like an EIM. In particular, these studies have examined potential grid operating reforms in the Western U.S., where hourly generator dispatch is still the norm and there has been significant discussion about the opportunity to move to an EIM. The EIM model is based on the successful use of an EIM in the Southwest Power Pool region. The California grid operator and the large interstate utility PacifiCorp launched an EIM in the fall of 2014, which has already provided $175 million in savings since its inception.[138]

Grid operating reforms like an EIM are by far the lowest hanging fruit for making the power system more flexible, and in fact they can be done at a negative cost to consumers. NREL calculated that an EIM would

[138] https://www.caiso.com/Documents/ISO-EIMBenefitsReportQ1_2017.pdf

provide annual benefits of $1.312 billion from faster dispatch and additional regional coordination benefits of $146 million from a region-wide EIM.[139]

Reducing the generation dispatch interval from one hour to 10 minutes and setting generation schedules at 10 minutes or less before the operating hour, both of which are accomplished under an EIM, are the single most important steps for improving the efficiency of power system operations and facilitating the integration of renewable energy. Setting schedules as close to real-time as possible greatly reduces the cost and reserve need for integrating wind energy because wind energy forecast error falls drastically as one gets closer to real-time, as shown in the chart below.[140]




The benefits or these reforms are not limited to reducing consumer cost and facilitating the integration of renewable energy by allowing more efficient operations, but also improving electric reliability through greater grid operator situational awareness and increased opportunity for sharing operating reserves. A FERC staff white paper[141] provided qualitative assessment of these reliability benefits. Recent work[142] by Synapse Energy Economics quantified the reliability benefits of an EIM. By assuming that the 2011 Southwest outage might have been prevented from spreading due to the real-time grid awareness provided by a well-designed and well-functioning EIM, Synapse Energy Economics calculated the potential reliability value of in EIM in that case at $775 million.

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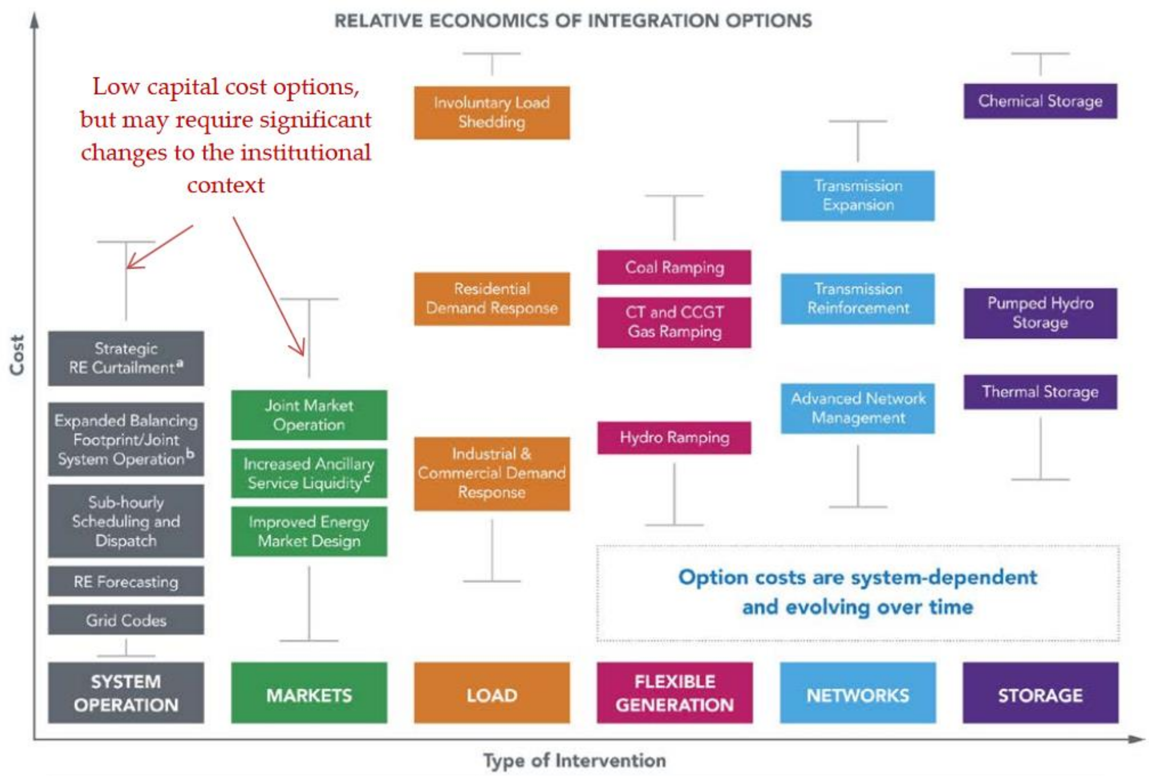
[139] http://www.nrel.gov/docs/fy13osti/57115.pdf, page xviii

[140] http://www.nrel.gov/docs/fy14osti/61035.pdf, page 4, with text and arrows added by AWEA

[141] FERC Staff, Qualitative Assessment of Potential Reliability Benefits from a Western Energy Imbalance Market, February 26, 2013, available at: https://www.caiso.com/Documents/QualitativeAssessment-PotentialReliabilityBenefits-WesternEnergyImbalanceMarket.pdf

[142] "Balancing Market Opportunities in the West: How participation in an expanded balancing market could save customers hundreds of millions of dollars." Prepared for the Western Grid Group October 10, 2014. Paul Peterson, Spencer Fields, Melissa Whited. Posted on the Western Grid Group website at: http://www.westerngrid.net/wp-content/uploads/2014/10/EIM-Synapse.pdf

The concept of a “flexibility supply curve” has been frequently discussed by NREL and other wind integration experts. For example, the following chart is a conceptual ranking of some of the grid resources that are available to provide flexibility, in order of increasing cost.[143] Its results are consistent with the findings presented above, namely that grid operating reforms and markets are the lowest cost options for providing flexibility, far lower than the cost of new energy storage. Grid operating reforms that achieve greater utilization of existing flexibility while more than paying for themselves by improving power system efficiency should be the first priority in efforts to make the power system more flexible.




Many analyses have looked at the relative value of various solutions to increase power system flexibility. LBNL analysis of the California grid found that accessing the geographic diversity of renewable resources, whether through grid operating reforms or transmission additions, was highly beneficial. That study also found increasing demand flexibility by introducing real-time retail prices was valuable, with both far more beneficial than the addition of energy storage.[144] Analysis in Europe found that more flexible conventional power plants and advanced wind and solar designs were more beneficial than the addition of energy storage.[145]

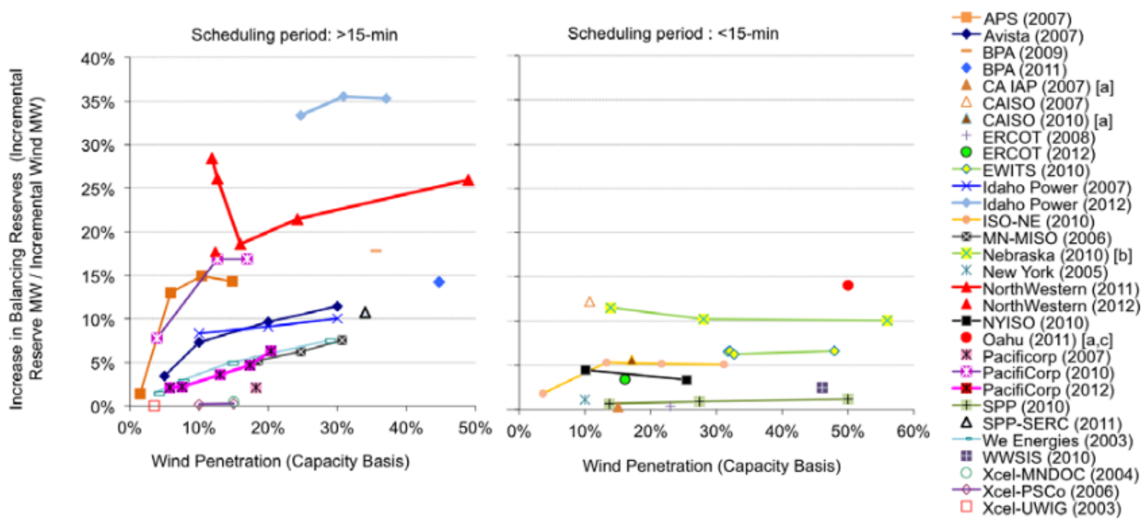
In most U.S. electricity markets, 5-minute generation dispatch intervals and setting generation schedules at 10 minutes or less before the operating hour are now standard practice. Hourly generation schedules and long lead times for setting generation schedules are a relic of an era before computers and modern communications equipment when generation schedule changes had to be communicated by telephone. By removing barriers to using existing flexibility on the power system and spare transmission capacity that

[143] http://www.nrel.gov/docs/fy16osti/64864.pdf
[144] https://emp.lbl.gov/sites/all/files/lbnl-6590e.pdf
[145] http://neon-energie.de/Hirth-Mueller-2016-System-Friendly-Wind-Power.pdf

is underutilized in the vast majority of hours, reforms like an EIM can greatly increase power system flexibility and efficiency at very low cost.

Concerns about the reliable and cost-effective integration of wind energy are now almost exclusively relegated to the parts of the U.S. that continue to use outdated grid operating practices. As described above, grid operators that use efficient practices, such as MISO and ERCOT, have found wind's impact on operating reserve needs and costs to be trivially small, even with more than 10,000 MW of operating wind generation.

The following chart from the DOE/Lawrence Berkeley National Laboratory Annual Wind Technologies Market Report also illustrates the value of efficient grid operating practices for greatly reducing the incremental operating reserve need and cost associated with integrating wind energy. Regions with efficient grid operating practices see much smaller integration costs, as shown in the chart below illustrating that regions with fast sub-hourly scheduling (on the right) have much lower wind-related operating reserve needs than regions with hourly scheduling.[146]




Grid operating reforms to create more coordinated and efficient generator dispatch across the Western U.S. provide more than enough flexibility to accommodate very high penetrations of renewable energy at a negative cost by drastically reducing operating reserve needs.[147] Given the demonstrated ability of regions with efficient operating practices to integrate large quantities of renewable energy, any obstacles or major cost associated with increased renewable energy integration are chiefly due to inefficient grid operating practices that need to be updated anyway.

[146] https://www1.eere.energy.gov/wind/pdfs/2012_wind_technologies_market_report.pdf, page 64
[147] http://www.nrel.gov/docs/fy13osti/60451.pdf

# 11. Isn't energy storage necessary to integrate wind?

No. Some of the most common questions about wind power involve the role of energy storage in integrating wind power with the electric grid. It is important to understand that very large amounts of wind energy can be reliably integrated at low cost without a need for energy storage, and that energy storage provides a variety of services and is therefore best viewed as a power system resource and not a resource for wind energy or any other individual resource. Moreover, as explained by the flexibility supply curve discussed in Chapter 10 above, energy storage is typically a more expensive source of flexibility than grid operating reforms that allow greater use of the flexibility that already exists on the power system today.

The reality is that, while several small-scale energy storage projects have been added in recent years, the U.S. has been able to add more than 80,000 MW of wind power to the grid without adding significant amounts of large-scale energy storage. Similarly, European countries like Denmark, Spain, Ireland, and Germany have successfully integrated very large amounts of wind energy without having to install new energy storage resources. In the U.S., numerous peer-reviewed studies have concluded that wind energy can provide 30% or more of our electricity without any need for energy storage.

The key to doing so lies in using the sources of flexibility that are already present on the electric grid. As discussed earlier, grid operators constantly accommodate variability in electricity demand and supply by increasing and decreasing the output of flexible generators and other sources of flexibility. A tremendous amount of flexibility has been built into the power system to accommodate large and abrupt swings in electricity supply and demand. Because these power plants and other sources of flexibility have already been built, it is almost always much cheaper to use this flexibility than to build new sources of flexibility like energy storage facilities.

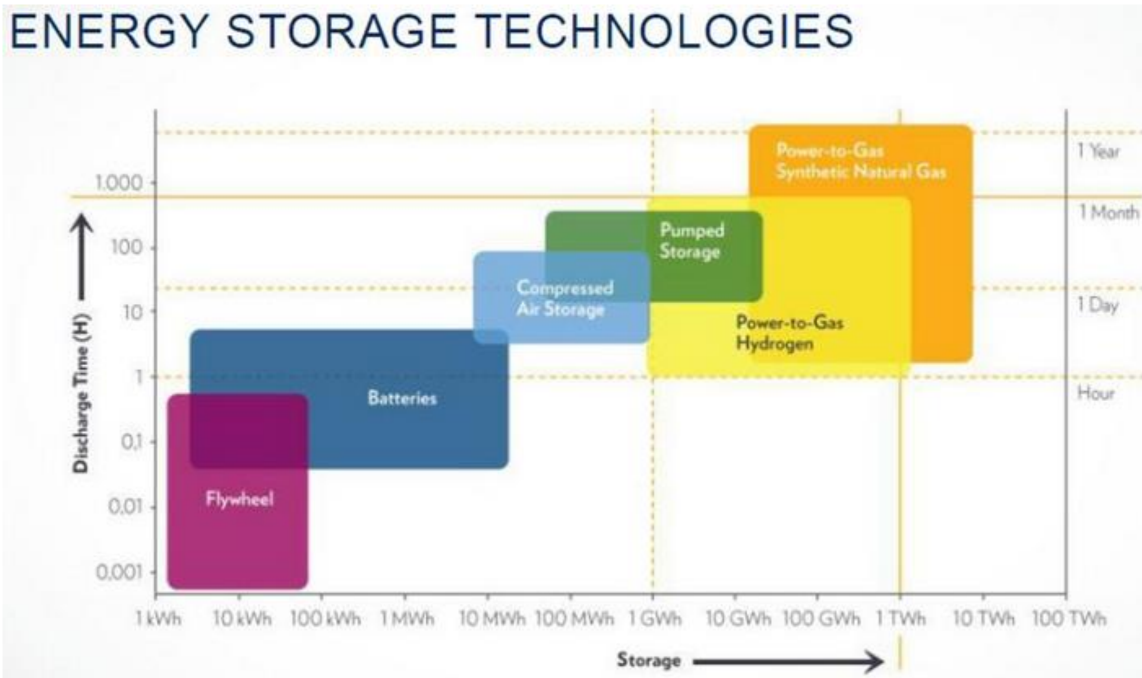
While continuing advances in energy storage technology can make it more economically competitive as a source of grid flexibility, and improving the performance and reducing the cost of battery storage remains critical for enabling greater electrification of the transportation sector, it is important to remember that resources like wind energy can already be cost-effectively and reliably integrated with the electric grid without energy storage.

The high cost of energy storage relative to other sources of flexibility, including those on the existing power system, is the chief reason why it is not more widely used today. In addition, many types of energy storage are poorly suited to help accommodate the specific type of variability that wind energy adds to the electric grid. As explained in the answer to Question 7 above, wind energy output shows very little variability over the minute-to-minute timeframe, with significant changes in output only tending to occur over time periods of 30 minutes or more. Fortunately, it is much cheaper to provide flexibility over these longer time periods using existing resources; as illustrated in the ERCOT data provided earlier, slower-acting reserves can be obtained at a fraction of the cost of faster-acting reserves. Some energy storage technologies, such as flywheels and advanced batteries, can be cost-effective for accommodating demand variability on the second-to-second time frame, but such technologies provide little to no value for wind integration.[148]

There are also fundamental limits to most energy storage technologies for providing the services needed at very high penetrations of renewable energy, such as those in excess of 50% annual penetration by energy. As illustrated below, no energy storage technologies in current widespread use are of sufficient scale to move dozens or even hundreds of GWh of energy hours or even days in time.[149] Pumped

[148] See, for example, https://emp.lbl.gov/sites/all/files/lbnl-6590e.pdf
[149] http://www.autoblog.com/2014/11/14/bibendum-2014-itm-power-make-free-hydrogen/

hydroelectric storage, with its ability to store large amounts of energy for long durations, is the only energy storage technology that is currently available that comes close to providing this type of service.




As discussed in the answer to Question 9, some people incorrectly assume that wind output must be "paired" or "firmed," i.e. have its variability leveled out, by storage or another resource to make it valuable to electric utilities or system operators. In reality, there is no need for individual power plants to provide constant power output; this is a good thing, as all power plants experience unexpected outages fairly frequently. As previously discussed, significant variability is already present on the electric grid due to changes in electricity demand and supply as consumers turn appliances on and off and power plants unexpectedly go out of service. Many changes in wind output actually cancel out opposite changes in electricity demand or supply. Therefore, attempting to "firm" wind can actually add to the total variability on the electric grid. Instead, it makes more sense for energy storage to be viewed as a system resource that can help even out the aggregate variability of all generators and all demand on the electric grid, and not used as a dedicated resource for a single generator or load. As a result, a wind plant is seldom the optimal location for deploying energy storage.

In certain rare situations, it could make sense to site energy storage near a wind plant. If a constraint on the transmission grid prevents a wind plant or group of wind plants from selling their full output on a consistent basis, it could be economical to store electricity that would otherwise have been curtailed. However, this type of application is a short-term fix; building out the transmission grid is typically the more optimal long-term solution to a transmission constraint.

In addition, it is important to keep in mind that while energy storage can be an economically attractive option in certain niche applications, such as small island power systems, this does not indicate that energy storage is an economic option on large mainland power systems. Small island power systems, due to geography and fuel mix, often lack low-cost sources of flexibility such as an ability to exchange power with neighboring grid operators. In contrast, mainland U.S. power systems can far more cost-effectively manage variability from all sources by using transmission to exchange power with a neighboring power system or access flexible resources.

While energy storage is not needed to integrate wind energy with the electric grid and is often not cost-effective, in some cases having certain types of energy storage on the grid can modestly reduce the cost of integrating wind. However, in some other cases, energy storage has been found to provide negative value for the integration of wind energy, even if the energy storage was provided at no cost.[150] Regardless, given the low cost of using existing flexibility to integrate wind energy, and grid operating reforms that enable far greater use of existing flexibility at negative cost, energy storage technologies should not be viewed as an essential tool for the integration of renewable energy.

The only form of energy storage that is currently operational on a large scale in the U.S. is pumped hydroelectric storage, with around 22 GW of installed capacity. In an illustration of that fact that storage is best viewed as a system resource, much of this storage was built to provide flexibility to help accommodate the significant increase in nuclear generation that occurred during the 1960's, 70's, and 80's. Just as it is typically not economic for wind plants to increase their output in response to grid demands, all U.S. nuclear plants and many coal plants tend to provide little to no flexibility.

Thus, all inflexible generators benefit when other sources of flexibility, including energy storage, can relieve them of having to accommodate changes in electricity supply and demand. In fact, studies in the Netherlands[151] and Ireland[152] found that coal plants were the primary beneficiaries of energy storage. Energy storage allowed coal power plants to run more at night, with this low-cost energy being stored and used to displace more expensive natural gas generation during the day, interestingly causing a net increase in electric sector carbon dioxide emissions in those cases. In the U.S., DOE data show that pumped hydro storage use declined drastically in 2012 and 2013 when abnormally low gas prices created an incentive for coal plants to begin cycling their output, reducing the need for storage to provide the flexibility that it had previously been uneconomic for coal plants to provide.[153]

While energy storage technologies may currently have difficulty competing economically with conventional sources of flexibility – especially for accommodating the more gradual variability most relevant for wind integration – continuing advances in energy storage technology can make energy storage more competitive as a provider of grid flexibility. For example, there is significant potential for the batteries of plug-in vehicles to be used as energy storage for the grid, particularly by simply altering the rate of charging of these batteries and therefore avoiding any cycling-related impacts to battery life, because the expense of those batteries would largely be covered by the fuel savings they provide to the vehicle owner. While the potential of such technologies is exciting, it is important to remember that resources like wind energy can already be cost-effectively and reliably integrated with the electric grid without energy storage.

[150] https://emp.lbl.gov/sites/all/files/lbnl-6590e.pdf
[151] http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=4463799&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D4463799
[152] http://econpapers.repec.org/article/eeeenepol/v_3a39_3ay_3a2011_3ai_3a4_3ap_3a1965-1974.htm
[153] https://www.eia.gov/electricity/data/browser/#/topic/0?agg=2,0,1&fuel=01&geo=g&sec=g&linechart=ELEC.GEN.HPS-US-99.A&columnchart=ELEC.GEN.HPS-US-99.A&map=ELEC.GEN.HPS-US-99.A&freq=A&ctype=linechart&ltype=pin&rtype=s&pin=&rse=0&maptype=0

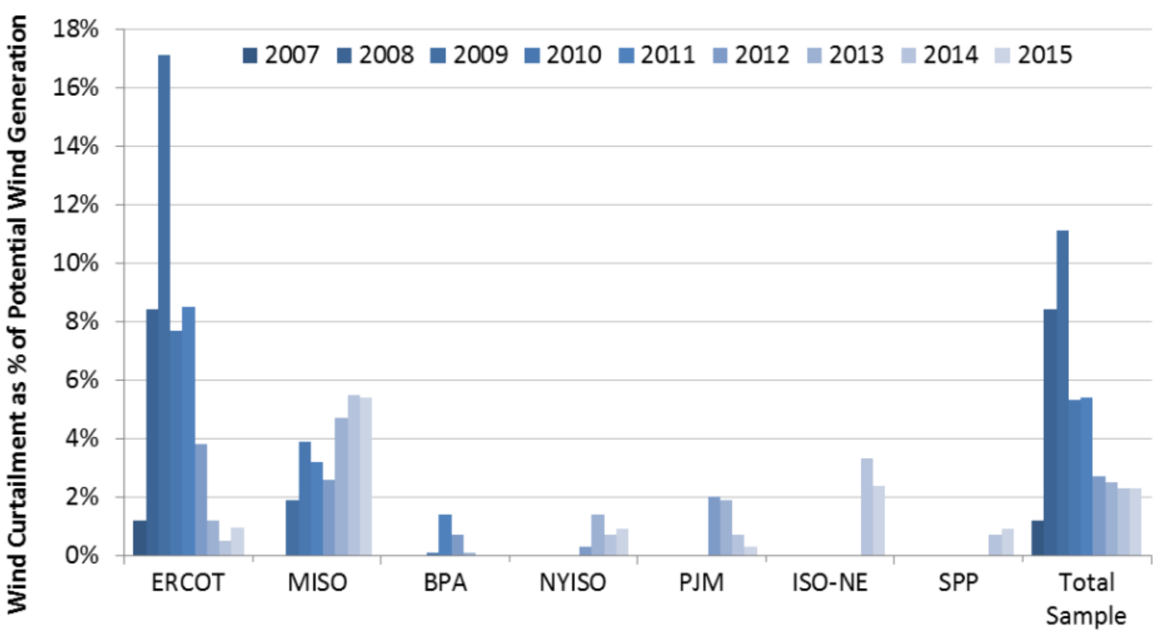
# 12. Why is some wind power curtailed? How does time of production affect the value of wind energy?

In some areas the growth of wind energy has outpaced the addition of transmission. At times this has required reducing the output of wind plants during certain hours until new transmission is added. However, as long-needed grid upgrades are completed, wind curtailment is being virtually eliminated, as are occurrences of negative electricity prices. Regardless of when it is produced, wind energy always has high economic value, particularly once the environmental and public health costs of fossil fuel generation are taken into account.

The majority of curtailment in the U.S. is caused by wind deployment outpacing the development of transmission.[154] When the output of any power plant exceeds the capacity of a transmission line to carry that power to customers, the output of that power plant must be reduced. Wind plants are able to quickly and accurately reduce their output when directed to do so by the grid operator or a market signal.

Some have incorrectly claimed that this curtailment is occurring because of the variability, or other attributes, of wind energy. In reality, any power plant located behind a transmission constraint and facing the same situation would have had its output curtailed.

Transmission upgrades are greatly reducing the transmission congestion that has forced the curtailment of some wind generation in some areas. As detailed in the table below,[155] curtailment of wind generation has been trending down nationally, most notably in ERCOT, where curtailment fell from 17.1% of wind generation in 2009 to only around 1% in 2015.  As additional transmission was brought online through the Competitive Renewable Energy Zone (CREZ) process and changes were made to improve the efficiency of ERCOT's operations, curtailment declined.[156]




[154] http://www.nrel.gov/docs/fy14osti/60983.pdf
[155] Available at: https://emp.lbl.gov/sites/default/files/2015-windtechreport.final_.pdf, page 41
[156] For more information, see: http://www.eia.gov/todayinenergy/detail.cfm?id=16831#

However, curtailment remains a concern in other regions. Just as Texas was able to virtually eliminate wind curtailment by building the CREZ transmission lines, MISO's Multi Value Project transmission lines and pending upgrades in other regions will greatly reduce this curtailment.

Transmission is the only long-term and economically viable solution to curtailment. Energy storage, demand response, smart grid, and other commonly proposed solutions are too small and often in the wrong location to meaningfully reduce curtailment, though they can provide other valuable services to the power system. Deploying demand response, energy storage, or other solutions does not help with wind curtailment unless it is located on the same side of a transmission constraint as a wind plant. Because most wind plants are located in remote areas, there are typically few large sources of electricity demand, and therefore opportunities for demand response, located on the same side of a transmission constraint as a wind plant. More importantly, transmission is the only resource of sufficient size to deliver the hundreds if not thousands of MWh of wind generation that are being curtailed.

Transmission congestion can cause electricity prices to temporarily go to zero or even lower, and this is an efficient market signal for the most expensive generators in that area to reduce their output. Some have mistaken this as a sign that wind generation has low value in general, or misinterpreted the localized negative prices as indicating that there is no need for wind generation anywhere on the power system. In reality, these localized negative prices go away when grid upgrades are completed, as the wind energy is then able to reach customers elsewhere on the power system who have always had a demand for that energy. Again, transmission is the solution, as there is always demand for electricity somewhere.

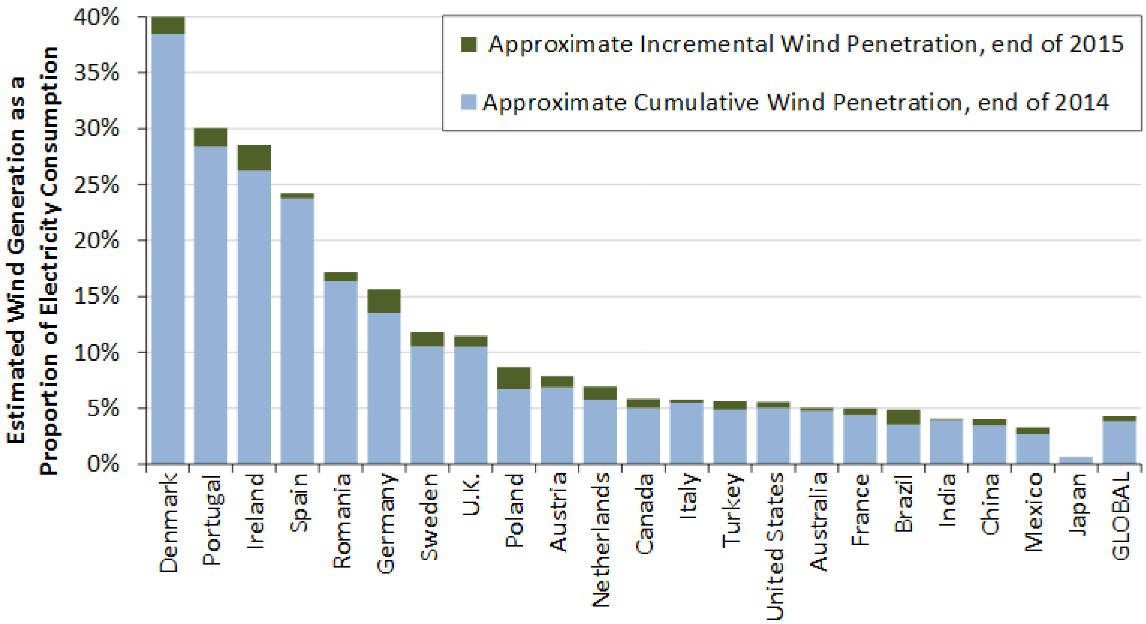
Even when transmission congestion causes negative prices, this does not mean that wind generation has low societal value. For example, let us suppose 7501 MW of wind generation are being produced behind a transmission constraint that only allows 7500 MW of wind output to reach consumers. As the wind production exceeds 7500 MW, the market price on that section of the grid will drop from the price set by the production cost for the system's marginal fossil-fired power plant to zero or even negative. The compensation for all 7500 MW of wind generators would fall to the zero or negative clearing price, even though the 7500 MW of wind generation that continues to pass through the transmission constraint continues to offset 7500 MW of fossil generation and reduce total system production costs by as much as before. Even though the market price dropped drastically to zero, the total societal value of reduced power system production costs remains the same.

Some have also expressed concerns that wind production during off-peak periods has low value. In reality, wind energy has high value regardless of when it is produced because grid operators use wind electricity to displace the output of the most expensive power plant that is currently online, which is almost always the least efficient fossil-fired power plant that is operating. Regardless of when it is produced, a MWh of wind energy displaces a MWh that would have been produced by burning natural gas, coal, or occasionally oil. As a result, substituting zero fuel cost wind energy for high marginal cost fossil fuel energy always directly reduces the fuel cost and emissions of the power system.

While the efficiencies of power plants vary slightly from one generator to another, in most cases these variations do not significantly change the value of the fuel saved by wind energy. This is even more so the case when one incorporates the negative environmental and public health externalities of fossil fuel use into the equation. Without externalities, it may appear that off-peak wind production that offsets lower production cost coal generation has lower value than wind that produces on-peak and offsets natural gas generation, but once coal's far larger environmental and public health costs relative to gas are accounted for, the value of off=peak wind production becomes far higher.

# 13. What has been Europe's experience with renewable energy?

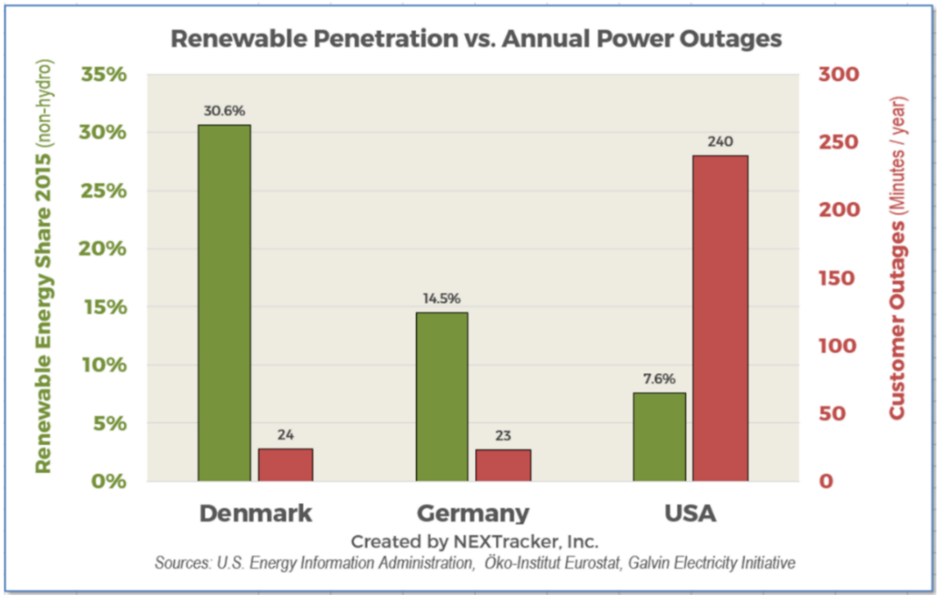
European nations have demonstrated that wind energy can reliably provide an even larger share of generation, with Ireland, Spain, and Portugal obtaining 24-30% of their electricity from wind on an annual basis, and Denmark at nearly 40%.[157]




Wind energy leaders Denmark, Ireland, Spain, Germany, and the Netherlands all have some of the most reliable power systems in the world, and they have seen their reliability improve significantly as they have increased their use of wind energy.[158] Germany's power system is the most reliable in Europe, and it has grown even more reliable as Germany has greatly increased its use of renewable energy in recent years.[159] The chart below confirms that Denmark and Germany power systems are 10 times more reliable than the U.S. power system.[160]

This is not to claim that renewables are the primary cause of the high reliability in these countries, as the most important factor in preventing customer outages is the resilience of the low-voltage distribution system for preventing localized outages. However, the data clearly does not support the claim that increasing use of wind energy has harmed European electric reliability, particularly the dubious claim that localized reliability problems have been caused by wind energy.[161]

[157] https://emp.lbl.gov/sites/default/files/2015-windtechreport.final_.pdf, page 7
[158] http://cleantechnica.com/2012/09/12/german-grid-reaches-record-reliability-in-2011-thanks-to-renewables/
[159] http://spectrum.ieee.org/energywise/energy/the-smarter-grid/germanys-superstable-solarsoaked-grid
[160] https://www.linkedin.com/pulse/response-rick-perry-regarding-renewables-grid-stability-daniel-shugar
[161] For an example of the false claims being made about European reliability, see http://instituteforenergyresearch.org/analysis/germanys-green-energy-destabilizing-electric-grids/




These countries' carbon emissions have also drastically decreased as they have ramped up their use of renewable energy over the last decade, disproving the myth[162] that European expansion of renewable energy has not delivered the expected emissions reductions. Others have also comprehensively rebutted these myths about reliability and emissions reductions.[163]

As shown in the table below, there is a very strong relationship between greater use of wind energy and a reduction in the carbon intensity of a country's electric sector, with Europe's wind energy leaders significantly outperforming the average reduction in electric sector emissions intensity for European OECD countries. Germany's carbon emissions would have fallen even further had it not drastically reduced its use of nuclear generation at the same time for unrelated reasons following the events at the Fukushima reactor in Japan.[164]

| Country | 2002 wind % | 2012 wind % | 2002-2012 decrease in electric sector emissions/MWh |
|---|---|---|---|
| Denmark | 12.41% | 33.42% | 41.35% |
| Portugal | 0.79% | 22.01% | 30.62% |
| Spain | 3.81% | 16.63% | 30.14% |
| Ireland | 1.54% | 14.53% | 28.08% |
| Germany | 2.70% | 8.05% | 12.78% |
| OECD Europe | 1.09% | 5.73% | 12.49% |

162 http://instituteforenergyresearch.org/analysis/germanys-renewable-energy-transition-misses-carbon-reduction-goals/
163 See, for example, https://www.rmi.org/news/debunking-renewables-disinformation-campaign, http://blog.rmi.org/separating_fact_from_fiction_in_accounts_of_germanys_renewables_revolution, https://twitter.com/EvaStegen/status/821371069097451521
164 https://www.agora-energiewende.de/fileadmin/Projekte/2017/Jahresauswertung_2016/Die_Energiewende_im_Stromsektor_2016_EN.pdf

Europe's expansion of renewable energy has also significantly improved its energy independence by reducing its dependence on natural gas imported from Russia. Providing Germany's wind generation in 2012 with gas generation would have required around 370 BCF of gas, 38% of Germany's total gas imports from Russia. Total Europe wind production would have required 2 TCF of gas to replace that energy, 67% of the gas shipped through Ukraine and 35% of total Russian exports to Europe.[165]

Reliably and cost-effectively integrating large amounts of renewable energy will be even easier in the U.S., as American renewable resources are more diverse and produce more energy more consistently. The U.S. power system is larger and more flexible than that in most of Europe, with abundant hydroelectric resources, flexible gas generation, and more weather-driven electricity demand variability that, as explained above, cancels out much of the variability of renewable energy. In contrast, Ireland is essentially an electrical island with minimal transmission ties and an inflexible generation fleet, and Spain and Portugal have similarly succeeded with minimal transmission ties to neighbors.

[165] IEA and EIA data

# 14. What is wind's net impact on emissions?

Wind energy greatly reduces emissions of carbon dioxide and other pollutants. Analysis using an EPA tool demonstrates that wind energy reduced carbon dioxide emissions by 159 million Metric tons in 2016,[166] and those savings continue to grow as more wind energy is installed. Wind energy also greatly reduces emissions of sulfur dioxide, nitrogen oxides, mercury, and other air pollutants, as well as reducing water usage and other environmental impacts of fossil fuel use.

Some have sought, without evidence, to undermine the large environmental benefits of wind energy by propagating the myth that wind's pollution reductions are smaller than expected because of impacts on the efficiency of fossil-fired power plants due to cycling.[167] The reality is that because renewable variability is a small contributor to total power system variability, renewable variability has a small impact on the cycling of conventional generation.

An NREL analysis examined the impact of cycling on wind's emissions savings based on real-world hourly emissions data collected at all power plants in the Western U.S., and the results conclusively show cycling has a "negligible" impact on wind's emissions savings.[168] NREL's study found that with wind and solar providing 33 percent of the electricity on the Western U.S. power system, one MWh of wind energy would save more than 1190 pounds of carbon pollution on average, with those savings reduced by only 0.2 percent, or 2.4 pounds, as a result of increased cycling of fossil-fired power plants.[169] Grid operator analysis in the United Kingdom also concludes that the impact of wind generation on reserve needs is very small, and that variability reduces wind's emissions benefits by less than 1/10th of 1 percent, or 0.1 percent.[170]

The PJM renewable integration study found similar results, with total emissions being reduced at the expected proportional rate as wind generation levels increased.[171] Moreover, total generator cycling costs actually decreased in the high renewable energy case in PJM's analysis.[172] NREL has also confirmed that the addition of any low-cost generation will increase the cycling of other generators.[173]

A related myth is that retaining or building new capacity to provide needed flexibility will mitigate the pollution reduction benefits of wind energy. This claim fails to understand that retaining or building generating capacity has a negligible impact on emissions as emissions are tied to energy, not capacity. Building more natural gas plants or keeping existing fossil-fired power plants around does not significantly impair efforts to reduce emissions, as power plants that are being used to provide capacity and flexibility only run during the small number of hours per year when those services are needed. Moreover, any MWh produced by that plant will directly displace MWh that would have come from another fossil-fired power plant, so there is essentially zero impact on total emissions.

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[166] AWEA Annual Report 2016; http://awea.files.cms-plus.com/FileDownloads/pdfs/AWEA_Clean_Air_Benefits_WhitePaper%20Final.pdf
[167] For example, see http://www.wsj.com/articles/SB10001424052748703792704575366700528078676
[168] http://www.nrel.gov/docs/fy13osti/57874.pdf
[169] Available at https://www.nrel.gov/grid/wwsis.html
[170] http://www.gizmag.com/uk-national-grid-wind-data/28046/
[171] http://www.pjm.com/~/media/committees-groups/subcommittees/irs/postings/pjm-pris-final-project-review.ashx
[172] Page 33 at http://www.pjm.com/~/media/committees-groups/subcommittees/irs/postings/pris-executive-summary.ashx shows total cycling costs are $870 million in the base case and $500 million in the renewable case.
[173] http://www.nrel.gov/docs/fy11osti/51860.pdf

Generating capacity itself causes no fuel use or emissions. Generating capacity, rather than actual dispatched energy, is what is primarily needed for providing operating reserves, particularly the slower-acting reserves that do noticeably increase in need at high renewable penetrations. The act of holding these reserves involves either keeping an operating power plant slightly below its maximum output or simply having a non-operating but quick-starting power plant sitting idle in case it is needed, neither of which causes a significant increase in fuel use or emissions, as confirmed by NREL's analysis. Even when these reserves are called upon, the quantity of generation and therefore emissions involved is minimal, and regardless this generation directly displaces generation that would have come from another fossil-fired power plant.

A final permutation of this myth is that increased levels of wind will cause generation to shift from more efficient gas combined cycle plants to more flexible but less efficient gas combustion turbines. This claim is refuted by all wind integration studies to date, which have found greatly reduced generation from gas combustion turbines at higher wind penetrations. For example, PJM's renewable integration study[174] shows Simple Cycle Gas Turbine (SCGT) generation significantly decreasing as the use of renewable energy increases. A California renewable integration study[175] shows gas turbine generation declining as renewable generation increases. This conclusion was also reached in the Minnesota Department of Commerce wind integration study.[176] Finally, the New England Wind Integration Study[177] also shows gas turbine generation declining as wind generation increases.

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[174] http://www.pjm.com/~/media/committees-groups/subcommittees/irs/postings/pjm-pris-final-project-review.ashx, at slide 55

[175] http://www.energy.ca.gov/2007publications/CEC-500-2007-081/CEC-500-2007-081-APB.PDF, page 98

[176] https://mn.gov/commerce/industries/energy/distributed-energy/mrits.jsp

[177] https://www.iso-ne.com/static-assets/documents/committees/comm_wkgrps/prtcpnts_comm/pac/reports/2010/newis_report.pdf, at page 213