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Modeling Sensitivities to the 20% Wind Scenario Report with the WinDS Model

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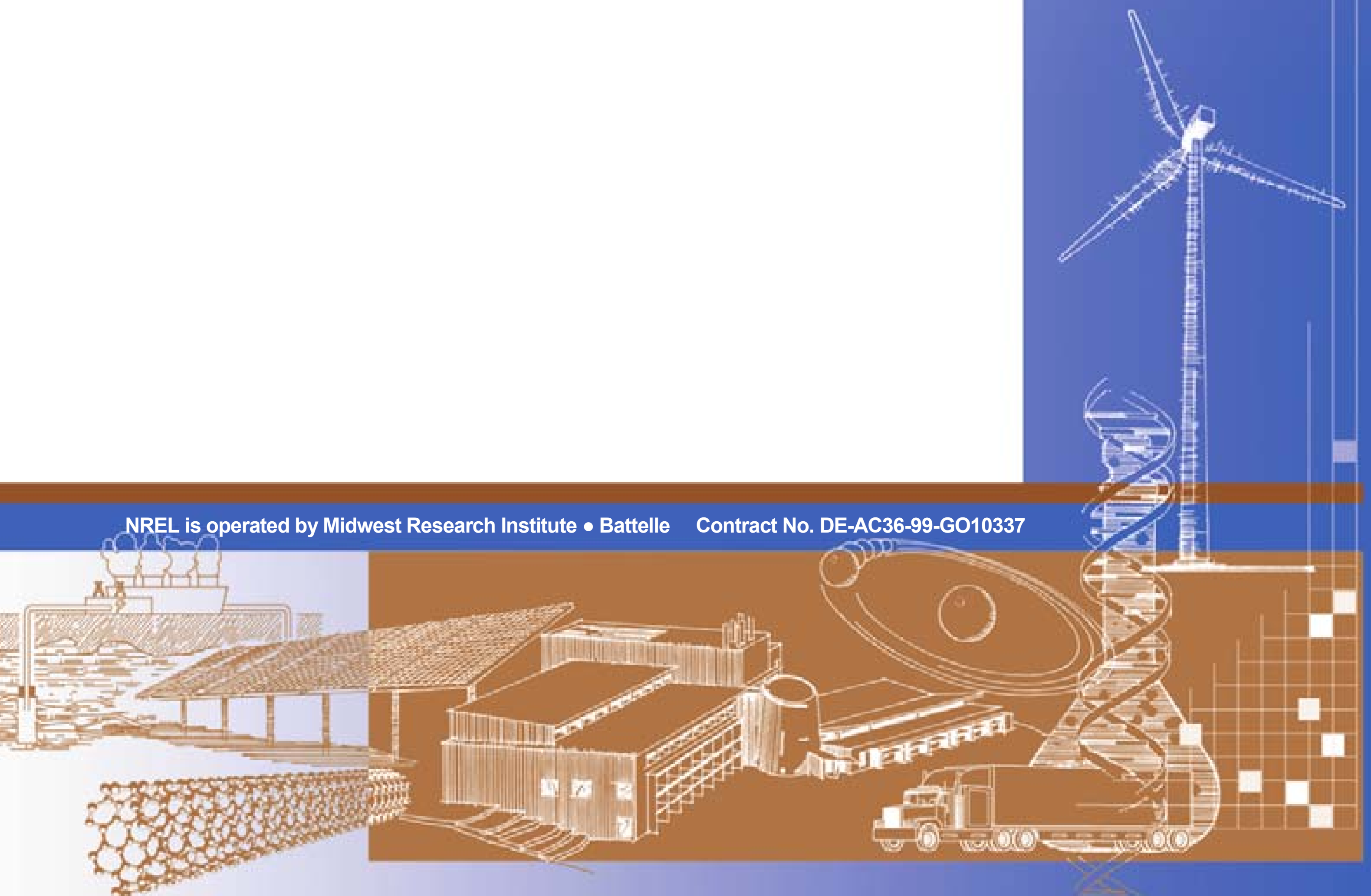

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1. Abstract

In May 2008, DOE published "20% Wind Energy by 2030"(ref), a report,[i] which describes the costs and benefits of producing 20% of the nation's projected electricity demand in 2030 from wind technology. The total electricity system cost resulting from this scenario was modestly higher than a scenario in which no additional wind was installed after 2006. NREL's Wind Deployment System (WinDS) model was used to support this analysis. With its 358 regions, explicit treatment of transmission expansion, onshore siting considerations, shallow- and deep-water wind resources, 2030 outlook, explicit financing assumptions, endogenous learning, and stochastic treatment of wind resource variability, WinDS is unique in the level of detail it can bring to this analysis. For the 20% Wind Energy by 2030 analysis, the group chose various model structures (such as the ability to wheel power within an interconnect), and the wind industry agreed on a variety of model inputs (such as the cost of transmission or new wind turbines). For this paper, the analysis examined the sensitivity of the results to variations in those input values and model structure choices. These included wind cost and performance improvements over time, seasonal/diurnal wind resource variations, transmission access and costs, siting costs, conventional fuel cost trajectories, and conventional capital costs. This paper will start with the 20% Wind and No New Wind scenarios presented in the 20% Wind Energy by 2030 report and examine changes due to various sensitivities.

2. Introduction

The 20% Wind Scenario contained many assumptions based on the best possible information from a broad range of stakeholders, including the wind and utility industries as well as the modeling community. Conducting this analysis led to a variety of improvements and enhancements to the WinDS model. However, especially in the area of future characteristics of the electric sector and the wind industry, these could only be assumptions and not facts. These assumptions may have a significant impact on the results of the 20% Wind Scenario. Therefore, it is important to examine the sensitivity of various resultant metrics to these assumptions. To that end, a variety of sensitivities were conducted (and are still ongoing at the time of this paper) to examine the impact of various factors.

These are typical sensitivities, not wholesale deviations. Where possible, a tie to an alternate reality was developed. The magnitude of the sensitivity impacts the overall range of results, which are reported in this paper. Typically, the inputs are varied 20% higher and 20% lower than the values used in the original analysis. These sensitivities also do not address all possible variations of inputs but typically vary a single input at a time. The combination of variance across all inputs would be of interest but would be computationally intensive. As with the original 20% Wind Energy by 2030 approach, the analysis is done by comparing two runs of the model—one with a requirement of reaching 20% national wind generation (20% Wind scenario) and one with no additional wind capacity installed after 2006 (No New Wind scenario). This comparison allows us to determine the impact of wind, explicitly and separately from any other projections to 2030. To date, 33 sensitivities have been performed. The analysis compared results within groupings of sensitivities and looked for impacts. Also, results across all sensitivities have been aggregated to help determine a range for various metrics such as wind capacity by state.

3. Summary of 20% Wind Energy by 2030 analytic approach

Before discussing sensitivities, a short discussion of the "20% Wind by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply" report is in order. The report examined a single scenario requiring 20% wind in 2030, and the results included the amount of wind deployed in each state and the cost of adding this level of wind to the national grid. Figure 1 shows the deployment of wind by state. However, the report says nothing about the uncertainty associated with those levels of wind, especially out to 2030. By varying the assumptions via these sensitivities, we achieve a range of reasonable values for wind penetration in each state.

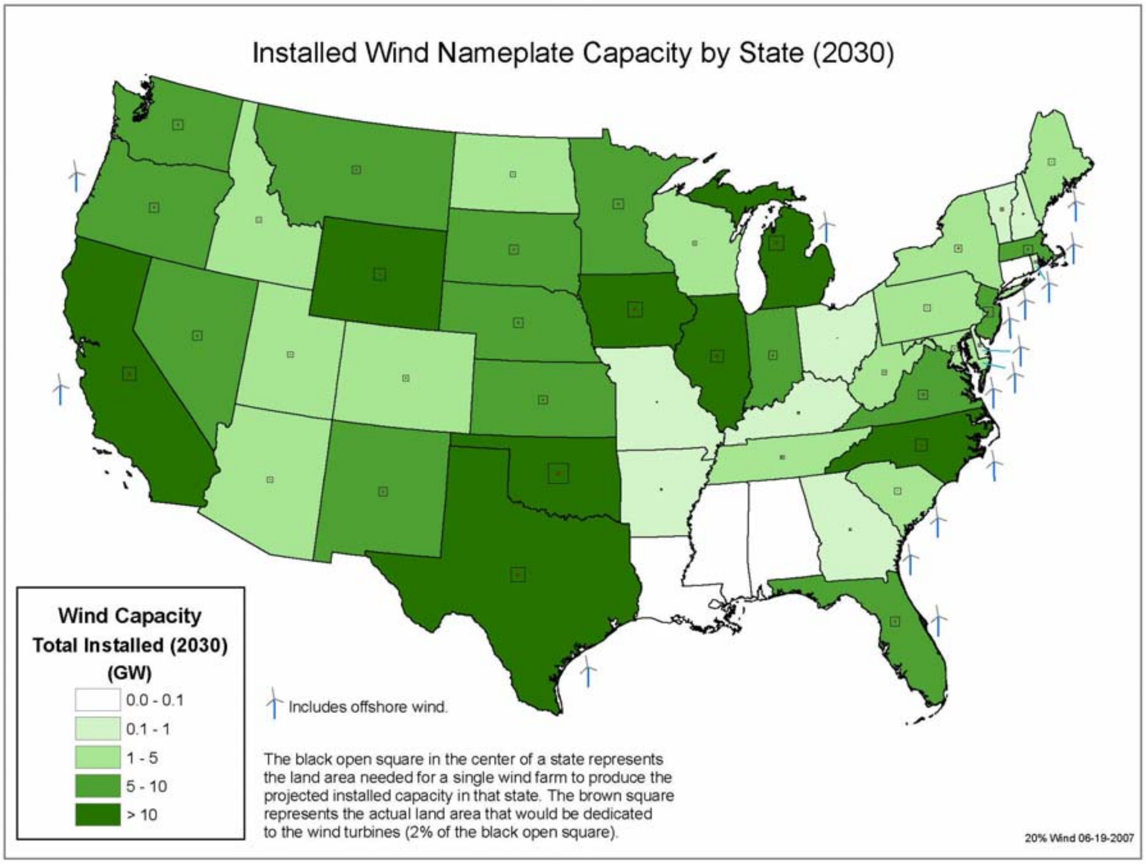
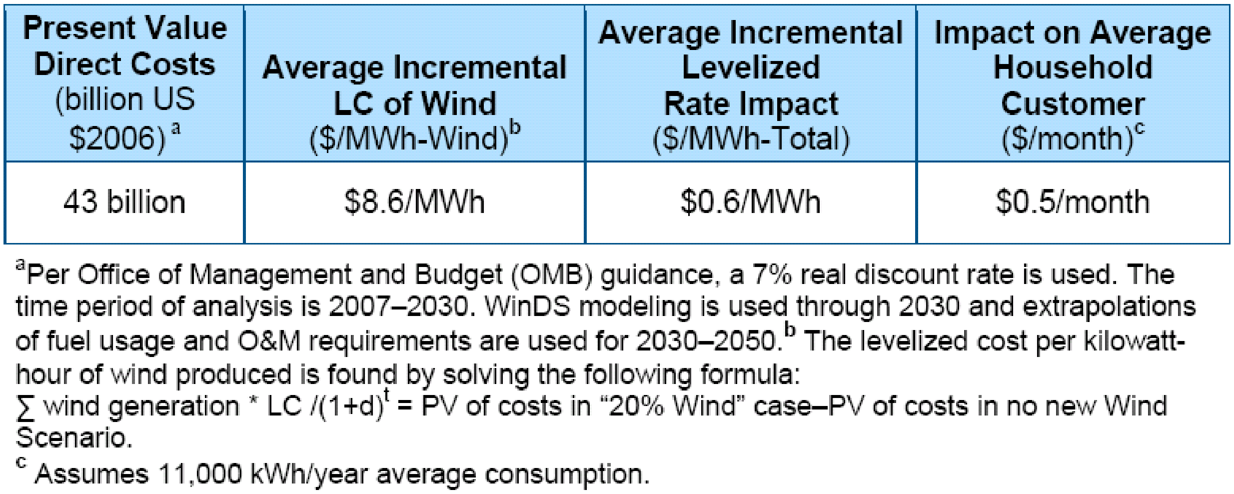


Figure 1. 20% Wind Scenario wind penetration by state in 2030

Table 1 documents the cost, generated by the WinDS model, of adding 300 GW (to get to 20% wind generation) of wind capacity to the national grid. This table focuses on direct electricity-sector costs. It ignores secondary effects such as the benefits of wind generation in reducing carbon emissions, or reducing water consumption. All costs are shown in US$2006, and the difference between the present values of the two cost streams is the total cost difference. In effect, WinDS calculates the incremental cost of achieving 20% wind (considering costs of capital, O&M, transmission and integration, and decommissioning) relative to a No New wind scenario in which only nonwind technologies compete for market share.

Table 1. Incremental Direct Cost of Achieving 20% Wind, Excluding Certain Benefits (US$2006)



Present Value Direct Costs (billion US $2006)[a]	**Average Incremental LC of Wind** ($/MWh-Wind)[b]	**Average Incremental Levelized Rate Impact** ($/MWh-Total)	**Impact on Average Household Customer** ($/month)[c]
43 billion	$8.6/MWh	$0.6/MWh	$0.5/month

[a]Per Office of Management and Budget (OMB) guidance, a 7% real discount rate is used. The time period of analysis is 2007–2030. WinDS modeling is used through 2030 and extrapolations of fuel usage and O&M requirements are used for 2030–2050.[b] The levelized cost per kilowatt-hour of wind produced is found by solving the following formula:

$\sum$ wind generation * LC $/(1+d)^t$ = PV of costs in "20% Wind" case–PV of costs in no new Wind Scenario.

[c] Assumes 11,000 kWh/year average consumption.

Figure 2 shows the net generation in 2030 of conventional energy and wind energy generation, with the two bars signifying the 20% wind and the no new wind scenarios. This figure also shows a significant reduction of energy generated from combined-cycle natural gas plants (Gas-CC) as well as reduced energy from new pulverized coal plants (Coal-New). Although each of our sensitivities will result in 20% wind, the mixture of the conventional technologies would change with varying assumptions.

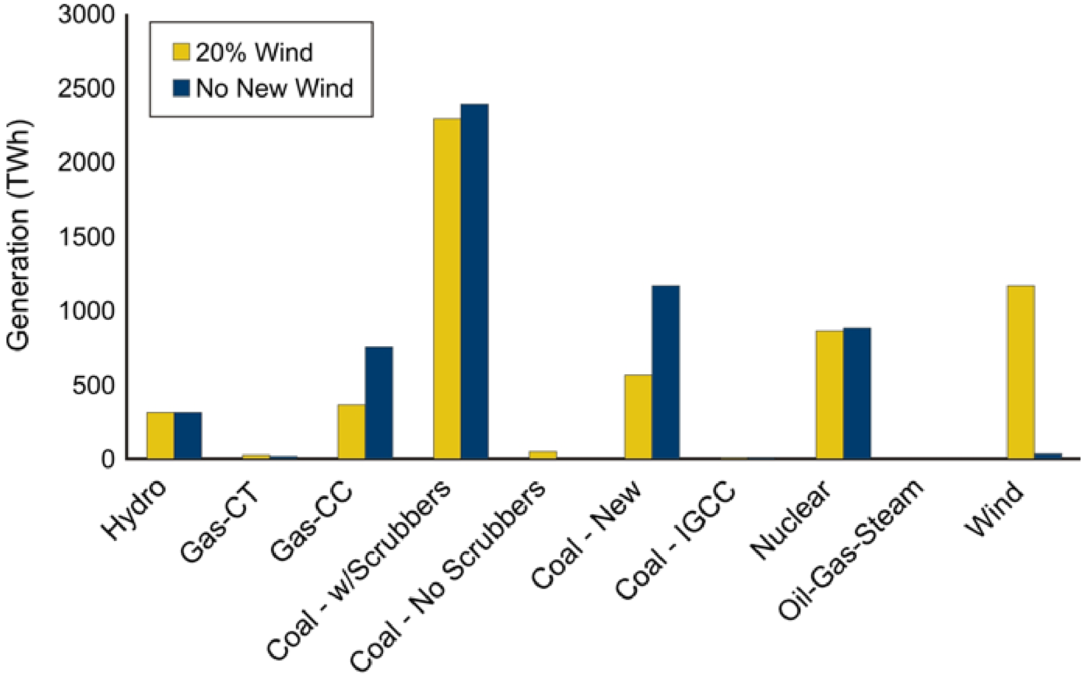


Figure 2. Generation by technology in 2030

4. Discussion of Sensitivities

The 20% Wind Scenario involved a variety of assumptions, ranging from specific costs to future transmission. Additionally, there are several characteristics within the WinDS model itself that impact the results. The goal of this activity is to examine, using a broad method of runs, the approximate impact of many of these assumptions and characteristics.

a. Overall Plan

The basic methodology examines the impact of these sensitivities by varying the value of the controlling variable or variables both above and below the value used in the 20% Wind Scenario. For example, where the original analysis used a particular set of values for the cost penalty associated with population density, the sensitivity would be 80% of that set of values and another sensitivity would be 120% of that set of values. The requirement of meeting 20% of the U.S. generation by 2030 with wind technology was maintained. Therefore, the primary impact of these sensitivities will be visible in the location of the wind deployment, the type of wind transmission (existing lines, new lines, local use), the incremental cost of the 20% wind scenarios (relative to the corresponding No New Wind scenarios), and the mix of conventional generators.

b. Families of Sensitivities

The sensitivities can be divided into several families of sensitivities that represent the overall aspect of the 20% Wind Scenario that is being examined.

Source of Costs

The first family of sensitivities is the source of costs. Within this grouping, we have included sensitivities to run the Energy Information Administration (EIA) costs (used within the Annual Energy Outlook), the costs used by the DOE EERE Government Performance and Results Act (GPRA) process (program goals), and the high and low fuel price trajectories from the Annual Energy Outlook (AEO). Finally, this family also will include sensitivities that activate a new fuel elasticity feature within the WinDS model.

Sensitivity 1: For the 20% Wind Scenario, a set of conventional and renewable costs (including capital, O&M, heat rate, capacity factor) were developed by Black and Veatch.[ii] For this sensitivity, the data set was replaced with the AEO 2007 input data from the U.S. EIA for the National Energy Modeling System (NEMS) model used with the Annual Energy Outlook. The EIA data is typically significantly lower than the Black and Veatch data, which includes the recent run-up in power-capacity capital costs.

Sensitivity 2: As with Sensitivity 1, the Black and Veatch data was replaced with data from the DOE goals used to generate the GPRA 2007 report.

Sensitivity 3: In the 20% Wind Scenario, the fuel prices from EIA for AEO 2007 were used (the high gas price and the reference coal price). For this sensitivity, the high gas and high coal prices were used. There was no significant difference and both sets of costs are below today's typically price.

Sensitivity 4: Conversely from Sensitivity 3, the prices for natural gas and coal were modified from the 20% Wind Scenario data set with the low natural gas and low coal price data sets.

Sensitivity 5: The WinDS model has been enhanced to include integrated price elasticities for natural gas and coal (and electricity demand). This scenario implements this capability to examine the impact of integrating price elasticities into the results. [Note: This scenario was not complete at time of publication.]

General Input Assumptions

The next family of sensitivities is an examination of the General Input Assumptions. These are characteristics of the model and assumptions that seem to drive the answers of the model. They include the national limit on sulfur dioxide (SO_2) emissions, seasonal and diurnal wind variations (as opposed to using the annual average wind capacity factor in the model), wind farm density, cost escalations due to dramatically increased global demand, and assumptions regarding energy efficiency deployment (i.e., load-growth assumptions). The final sensitivities within this family examine the impact of wind-resource data assumptions.

Sensitivity 6: In the 20% Wind Scenario, the national SO_2 limit imposed by the Clean Air Interstate Rule (CAIR) regulation was implemented. This effectively puts a cap on the amount of new coal capacity that will likely be built in the country, and forces old coal plants to buy SO_2 scrubbers. In this sensitivity, that constraint was removed allowing unlimited SO_2 emissions from the coal industry.

Sensitivity 7: Seasonal and diurnal wind variations were developed for the 20% Wind Scenario for each of the 358 regions within WinDS as well as each of five classes of wind for those regions. This variation was removed leaving only an annual average capacity factor across all seasons and diurnal time slices.

Sensitivity 8: Typically, a value of 5 MW/km2 is used for wind farm density, which translates the km2 of resource area into wind capacity potential. For this sensitivity, a value of 3.5 MW/km2 was used. [Note: This scenario was not complete at time of publication.]
Sensitivity 9: Deleted
Sensitivity 10: The state incentives, such as the renewable portfolio standard (RPS), were developed in early 2006 for the 20% Wind Scenario. These can have an impact, especially in states that would not add significant wind capacity without these mandates or incentives. Because these state incentives are changing frequently, this sensitivity was to use the most up-to-date state incentives possible. [Note: This scenario was not complete at time of publication.]
Sensitivity 11: As with Sensitivity 10, this varies the state incentives. This sensitivity removes all state incentives or mandates.
Sensitivity 12: This sensitivity adjusts the conventional power capital costs 20% above the Black and Veatch cost trajectories used in the 20% Wind Scenario.
Sensitivity 13: This sensitivity adjusts the conventional power capital costs 20% below the Black and Veatch cost trajectories used in the 20% Wind Scenario.
Sensitivity 14: The 20% Wind Scenario uses the AEO 2007 reference case to determine North American Electric Reliability Corporation (NERC)-level load growth rates to 2030. This scenario replaces that growth rate with that from the AEO 2007 Low Economic Growth case.
Sensitivity 15: The 20% Wind Scenario uses the AEO 2007 reference case to determine NERC-level load growth rates to 2030. This scenario replaces that growth rate with that from the AEO 2007 High Economic Growth case.

Industry Response
Another family of sensitivities deals with assumptions of how the wind industry responds to the significant demand for wind generation technology. For example, if the wind industry develops quickly in response to demand, wind capital costs will be lower than anticipated by the 20% Wind Scenario Report. Likewise, the wind industry could not grow and respond as quickly, resulting in higher costs. Separately, the offshore wind industry could develop more quickly or more slowly independently of the onshore wind industry. Independent from industry growth, the wind technology may or may not improve as expected within the 20% Wind Scenario analysis, resulting in flat capacity factor improvement or additional capacity factor improvement over what is currently expected.
Sensitivity 16: In this case, the offshore industry is assumed to expand more rapidly than expected in the 20% Wind Scenario, resulting in a future cost decrease 20% larger in magnitude.
Sensitivity 17: Similar to Sensitivity 16, but for both onshore and offshore wind industries, this sensitivity anticipates a 20% greater cost reduction over time to 2030.
Sensitivity 18: In contrast to Sensitivity 17, this sensitivity uses the starting 2006 onshore and offshore wind capital costs with no reduction to 2030. This implies constant growth pressure on the wind industry and slower growth, resulting in no cost reductions over time.
Sensitivity 19: This sensitivity anticipates no technology improvements from R&D. In this case, the capacity factors are used throughout to 2030 instead of the 20% Wind Scenario, which anticipates capacity factor improvements for all wind classes.
Sensitivity 20: The opposite of Sensitivity 19, this sensitivity anticipates advanced improvements in technology resulting in a 20% greater expected improvements in wind capacity factor from the 20% Wind Scenario.

Grid Impacts

Another family of sensitivities focuses on the impact of grid improvements, or lack thereof, on the results. Specifically, these sensitivities examine the impact of grid improvements that exceed what is expected by the 20% Wind Scenario. These improvements would result in lower transmission costs, larger balancing regions, and a greater amount of the existing grid available for new wind additions. Conversely, if grid operations and capacity do not expand as expected in the 20% Wind Scenario, there are several sensitivities that examine a grid with less availability for wind to use existing lines, a higher cost for transmission, and higher levels of cost to wheel power between control areas. This family also contains two sensitivities to the wind capacity value.

Sensitivity 21: The 20% Wind Scenario uses a complex loss-of-load-probability calculation method to calculate the capacity value of the marginal unit of wind for each class, in each wind region, for each period. In this scenario, the analysis looks at extreme capacity valuation of wind and sets the wind capacity value equal to the capacity factor, when it is normally much lower than this value.

Sensitivity 22: Contrary to Sensitivity 21, this scenario examines the other extreme and grants no capacity value to wind. Both sensitivities are extreme cases but will obviously bracket the correct scenario.

Sensitivity 23: In the 20% Wind Scenario, the availability of the existing grid was assumed to be 10%. This means that of the existing grid capacity crossing any boundaries—power control area (PCA) regions especially—10% of that capacity was assumed to be available for new wind capacity. The lines were assumed to be 90% filled with transport of existing capacity. For this sensitivity, that level was raised to 40%. This is more than a 20% increase but was deemed necessary to show significant switching of wind from new lines (more expensive) to existing lines (generally less expensive when available). This sensitivity also goes along with Sensitivity 28 for flex-firm transmission use. [Note: This scenario was not complete at time of publication.]

Sensitivity 24: The cost of new transmission construction in the 20% Wind Scenario is roughly $1,600/MW-mile for new lines. This scenario examines the situation with cheaper transmission costs (80% of $1,600/MW-mile). [Note: This scenario was not complete at time of publication.]

Sensitivity 25: Typically, in the WinDS model and especially for the 20% Wind Scenario, ancillary service requirements for wind are calculated at the NERC region level (wind surplus, operating reserve). However, the WinDS model recently has been enhanced by adding RTO (regional transmission organizations) boundaries. This scenario uses this new capability to examine the impact of calculating necessary wind ancillary service impacts at these smaller geographic regions (36 RTOs vs. 13 NERC regions). The expectation is that the costs will be higher because the impact of wind on the system will occur over a much smaller region. For example, wind surplus would have a smaller region to find a load to make use of it.

Sensitivity 26: Similar to Sensitivity 23, this one examines the availability of the existing grid. Instead of the 10% used by the 20% Wind Scenario or the 40% for Sensitivity 23, this one allows no new wind capacity to make use of the existing grid. This basically assumes complete congestion.

Sensitivity 27: Similar to Sensitivity 24, this one examines the cost of transmission by increasing it to 120% of the value used in the 20% Wind Scenario report. The anticipation is that more wind will be built using the existing grid and that wind will be built closer to load even though the resource might be slightly worse. [Note: This scenario was not complete at time of publication.]

Sensitivity 28: This is the scenario that takes a look at the "flex-firm" scenario, in which wind capacity forfeits the ability to serve load during the peak periods of the year. However, at all other times of the year, up to 40% of the existing grid is available. This is implemented by allowing wind to use 40% of the existing grid but receiving no capacity value. [Note: This scenario was not complete at time of publication.]

Sensitivity 29 and 30: In the 20% Wind Scenario, the cost to wheel power across power control areas (PCAs) was assumed to be zero. Going forward, it is anticipated that these wheeling charges would continue to diminish as larger balancing authorities are created. However, this may not develop as anticipated. Therefore, these sensitivities examine the presence of two levels of wheeling charges. Sensitivity 29 uses a wheeling charge o $1/MWh-"PCA crossed"; and Sensitivity 30 uses a charge of $5/MWh-"PCA crossed." As shown below, these charges result in less wind capacity in the Midwest and more wind capacity in the coastal areas closer to load.

Geographic Variations

The 20% Wind Scenario included regional variations in wind capital cost and transmission capital costs. There are sensitivities included that both increase and decrease these values. Additionally, the 20% Wind Scenario analysis included cost multipliers on wind for population density and the terrain roughness of the region, primarily because it's more costly to build wind capacity in areas that are mountainous or rugged, and that areas with high population density result in "NIMBYism" (not in my backyard) cost increases. Although these effects are true, the quantitative impact of these effects is undocumented and will likely change by 2030. Therefore, these sensitivities vary the impact of both the "slope penalty" and the "population density penalty".

Sensitivity 31: In the 20% Wind Scenario report, a capability to have different regional costs of transmission was implemented to allow for regional deviations from the national average price for new transmission. This adder was for both wind and conventional transmission that needed to be built. This adder was used in New England, New York, eastern PJM, western PJM, and California with a range of 40% higher transmission costs in New England to 20% higher costs in California. This sensitivity reduces those regional transmission costs adders to 80% of those values (so 40% adder drops to 32% adder).

Sensitivity 32: In the 20% Wind Scenario report, a population density adder was included on the wind capital costs to represent increased difficulty in siting wind farms in highly populated regions. Specifically, the highest population density in the country (New York City) has a doubling of wind capital costs. This cost adder drives development toward rural, unpopulated areas of the country. This scenario reduces the population cost adder to 80% of what it was in the report.

Sensitivity 33: Similarly, the WinDS model captures the fact that it's typically more expensive to build a wind farm in a mountainous area than in a flat plain. For each wind region, an average slope value is calculated and a cost is applied to the wind capital cost for that region based on that value. For an 8% average slope (quite mountainous), there is a 20% higher cost of wind capital cost. This is only for the installation portion of the wind capital cost, however, which is assumed to be 25% of the overall wind capital cost. This sensitivity adjusts those slope cost adders down to 80% of their value.

Sensitivity 34: Similar to the regional cost adders on transmission builds, the "regional cap cost adder" adds a regional cost adder to the capital cost (both conventionals and wind) based on regions of the country. This cost adder was applied in New England and added 20% to the capital cost of all new power technology builds. This sensitivity reduced this cost adder from 20% to 16% for New England.

Sensitivity 35: Similar to Sensitivity 31, this sensitivity impacts the regional transmission cost adder; but instead of decreasing it by 20%, this sensitivity increases it by 20%. This should incentivize more wind outside of the regions with these penalties.

Sensitivity 36: Similar to Sensitivity 32, this sensitivity adjusts the population density adder by increasing it 20% over the set of values used in the 20% Wind Scenario report. This should shift wind development from more populous to more rural areas.

Sensitivity 37: Similar to Sensitivity 33, this sensitivity modifies the slope penalty, but increases it by 20%. This should shift wind development from mountainous areas to more flat regions of the country.

Sensitivity 38: Similar to Sensitivity 34, this sensitivity adjusts the regional capital cost adder for all technologies (i.e., New England). This should result in even more development of electric capacity outside of New England and shipping the power into that region.

5. Specific Family Results

Each of these sensitivities could be examined in detail and in relation to all other sensitivities. However, for this paper, two methods of comparison were chosen. First, an examination of some of the comparisons within each family of sensitivities will be discussed. Second, an examination of the overall results across all sensitivities will be presented below.

Figure 3 illustrates, for several sensitivities (Sensitivities 16 through 20), the relative additional cost of reaching 20% wind generation versus having no additional wind. As shown in Table 1, this value was roughly $43 billion in the 20% Wind Scenario report. With some recent changes to the WinDS initial data set of conventional power plants, this value has changed, and so the results are presented as a percentage of the 20% Wind Scenario original case (shown in red at 100% on the left). This graph shows that if the wind industry expands quickly to efficiently meet the demands of reaching 20% wind generation—resulting in lower wind capital costs—that the overall cost of reaching 20% wind generation decreases somewhat. However, if the industry grows too slowly, resulting in manufacturing pressure and higher prices (slow_ind_growth), then the present value of the additional cost can jump by 50%. Likewise, if there is no wind technology improvement (capacity factors stay at today's level), the cost jumps even more dramatically to 270% of the initial 20% Wind Scenario. More optimistically, if R&D and other improvements enhance the wind technology even more than anticipated (with a higher capacity factor than expected), reaching 20% wind generation can actually save money for the system over the long run.

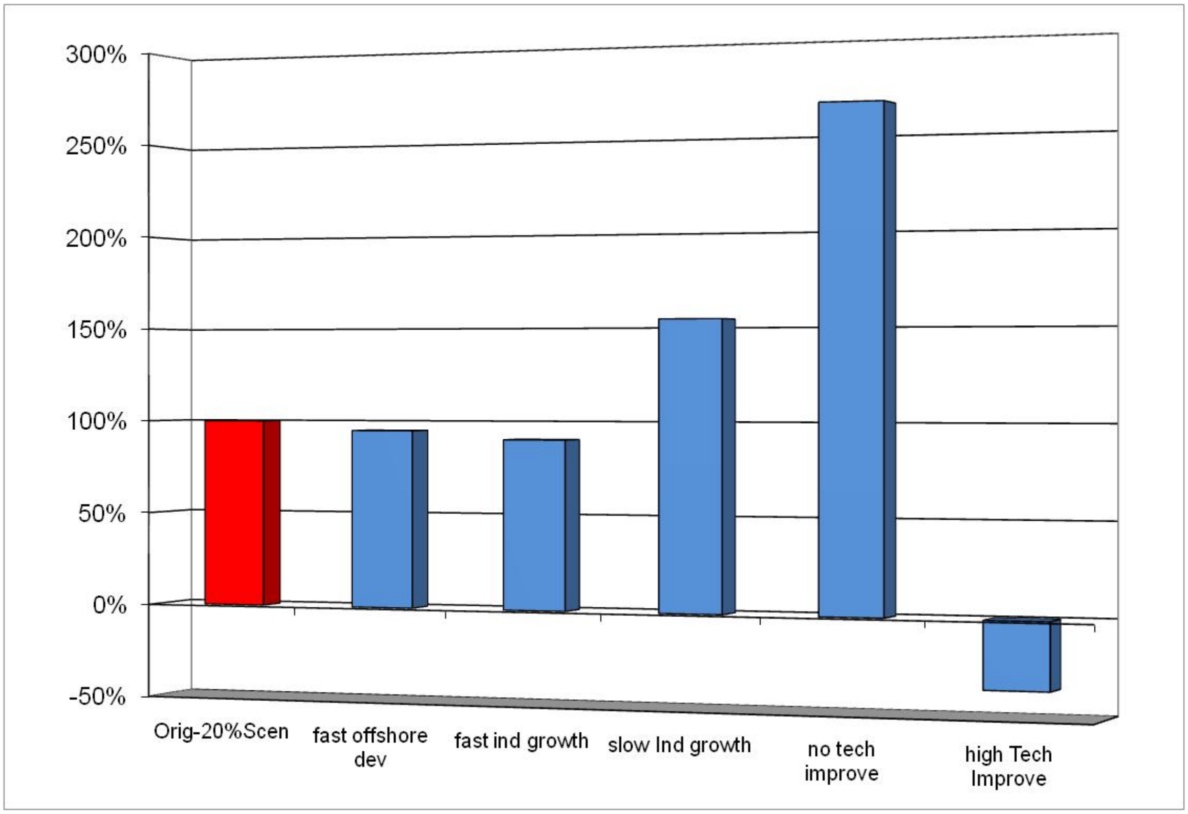


Figure 3. Impact of industry growth on overall cost trends

The analysis examined another family of geographical sensitivities (Sensitivities 31 to 38) to determine the impact on the transmission choices that the model made to get wind to load. The model can use existing transmission if it's available (for either onshore or offshore wind) or build a new transmission line (often more expensive). The results for the breakdown between onshore and offshore wind on new or existing transmission lines in Figure 4 show that the sensitivities that relate to the population density cost adder have the largest impact on the breakdown compared to the original 20% Wind Scenario case (on the far left). The other sensitivities do not significantly alter the breakdown into these four groupings. By increasing the population density cost adder, the model shifts more wind capacity generally from onshore to offshore (especially true on the East Coast, which has a high population density onshore but obviously no population offshore).

Additionally, wind capacity is shifted from onshore on existing transmission to offshore on new transmission lines. Interestingly, this means that instead of shifting to an onshore site farther inland and transmitting the power to the coast, the model chooses (with this set of offshore cost data) to shift significant amounts of wind capacity offshore.

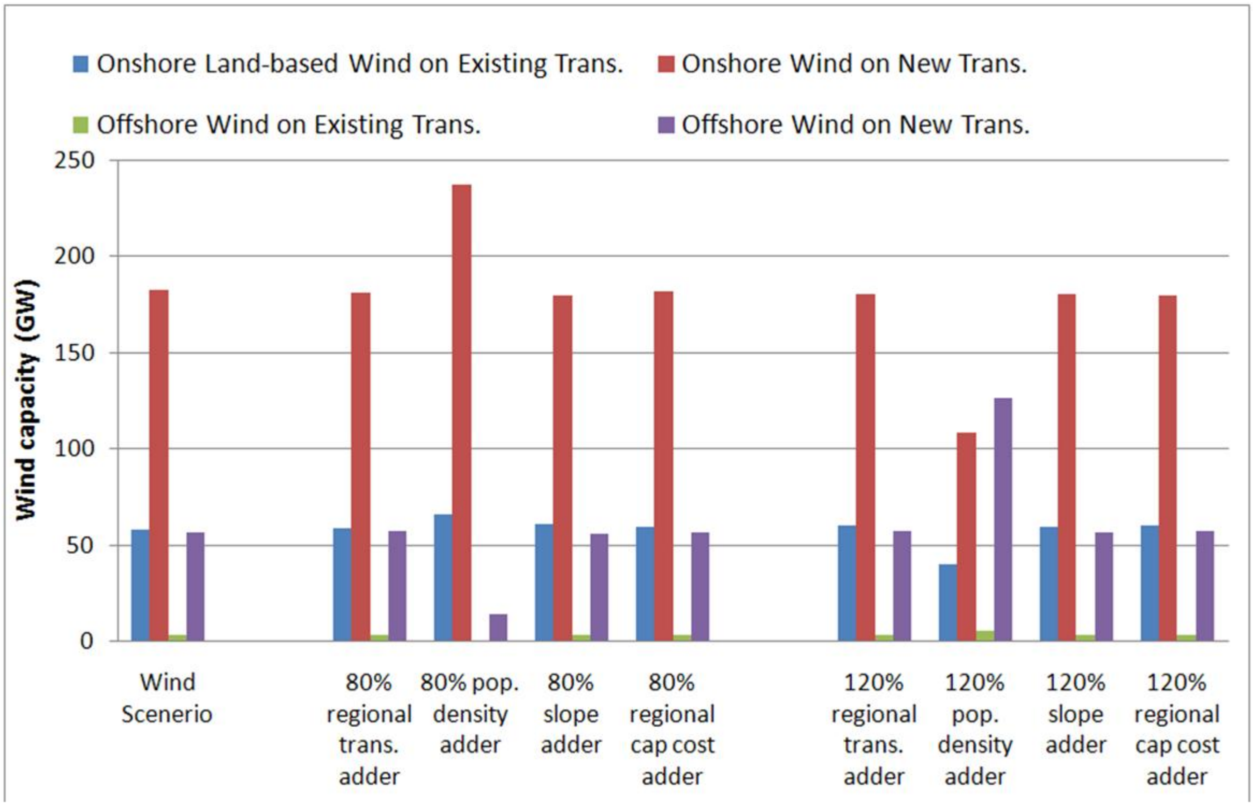


Figure 4. Breakdown of onshore vs. offshore and existing vs. new transmission lines for the geographical sensitivity family

By examining the same family of sensitivities, Figure 5 shows the impact on the overall cost of reaching 20% wind generation over the no wind case. Instead of plotting the total present value cost, this figure plots the additional cost in terms of $/MWH of wind (on the left axis) and the additional cost in terms of $/MWH of total system generation (on the right axis). As the graph shows, most of the geographic sensitivities have almost no significant impact on the additional cost. The one that does somewhat dramatically increase the cost is, again, the population density adder. This is expected because an additional significant cost was added to onshore wind in populated areas, and offshore wind typically costs more than onshore wind.

From a modeling perspective, these two graphs (Figures 4 and 5) show that the population density cost adder has a significant impact on the model results and, therefore, additional effort should be invested to verify and refine this cost adder. The other geographically based sensitivities don’t show much impact (at least from these two figures) and, therefore, do not need as much critical reexamination.

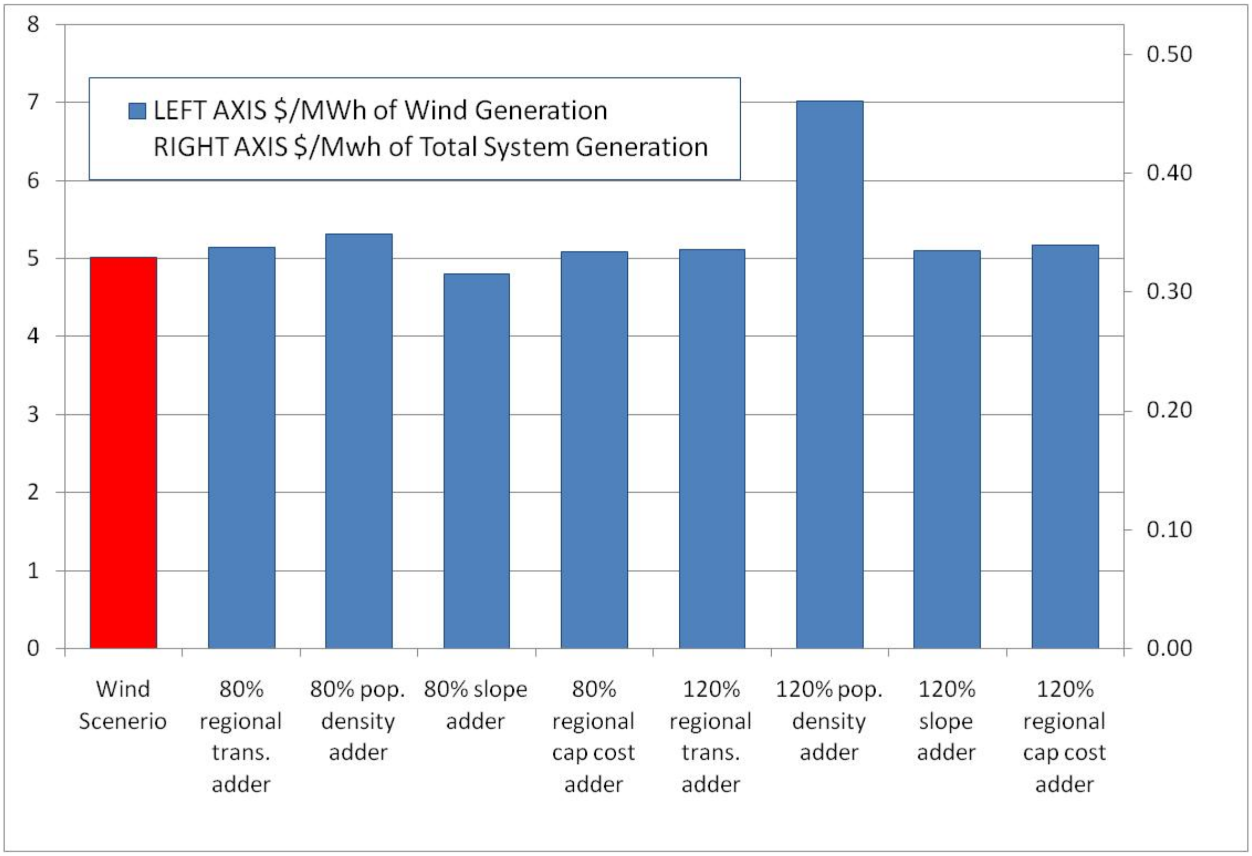


Figure 5. Additional cost of 20% wind generation for the geographical sensitivity family

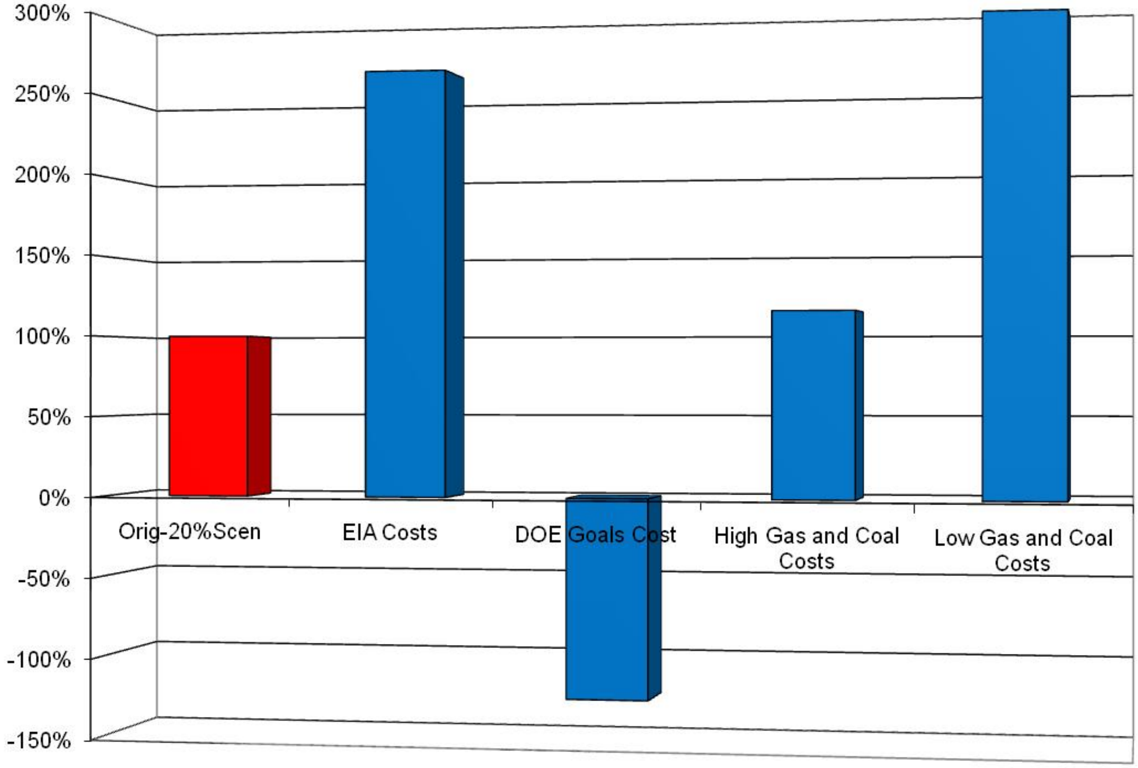


Figure 6. Additional cost of 20% wind for the Source of Costs sensitivity family

Figure 6 illustrates the additional cost necessary for reaching 20% wind generation using a variety of cost data sets that are typical (and complete) – Sensitivities 1 to 5. Using the EIA cost data set, which assumes minimal cost reduction and performance improvements, increases the cost of doing 20% wind, while using the DOE goals cost set (which implies significant cost reductions due to R&D improvements) results in a net present value savings to the system. As with the technology improvement sensitivities above, this shows that technology improvements can have a noticeable impact on the overall cost of reaching 20% wind generation. The final two bars show the impact of using high gas and coal costs and low gas and coal costs. The original 20% Wind Scenario used high gas prices from AEO 2007 and the reference coal prices. It seems that using high coal prices in addition to high gas prices results in a higher aggregate cost of reaching 20% wind generation. These results are counterintuitive and should be further examined. It should be noted that both of these sensitivities uses cost trajectories that are below today's gas and coal costs. It is highly unlikely that a significantly lower fuel-cost trajectory will become reality.

When one examines the current results from the Grid Impact Family of sensitivities (Sensitivities 21 to 30), it becomes apparent that these sensitivities impact future locations for wind capacity. Specifically, Sensitivity 30—which increases the pancake cost (or wheeling cost) for shipping power on the existing grid across PCA boundaries—shifts wind capacity builds from the center of the United States toward the large load centers on the coasts. This is because, by significantly increasing the cost of shipping power across many PCAs, it makes some wind sites that are closer to loads slightly more cost-effective than those that are farther away. Figure 7 shows the change in wind capacity by state for this sensitivity. Red indicates a decrease in wind capacity between this scenario and the original 20% Wind Scenario; blue indicates an increase in wind capacity. Therefore, if the anticipated improvements in reducing and eliminating the cost of wheeling power between utility regions doesn't occur, more wind capacity will be built closer to large loads and in high quality wind resource sites but less populated areas, although somewhat less.

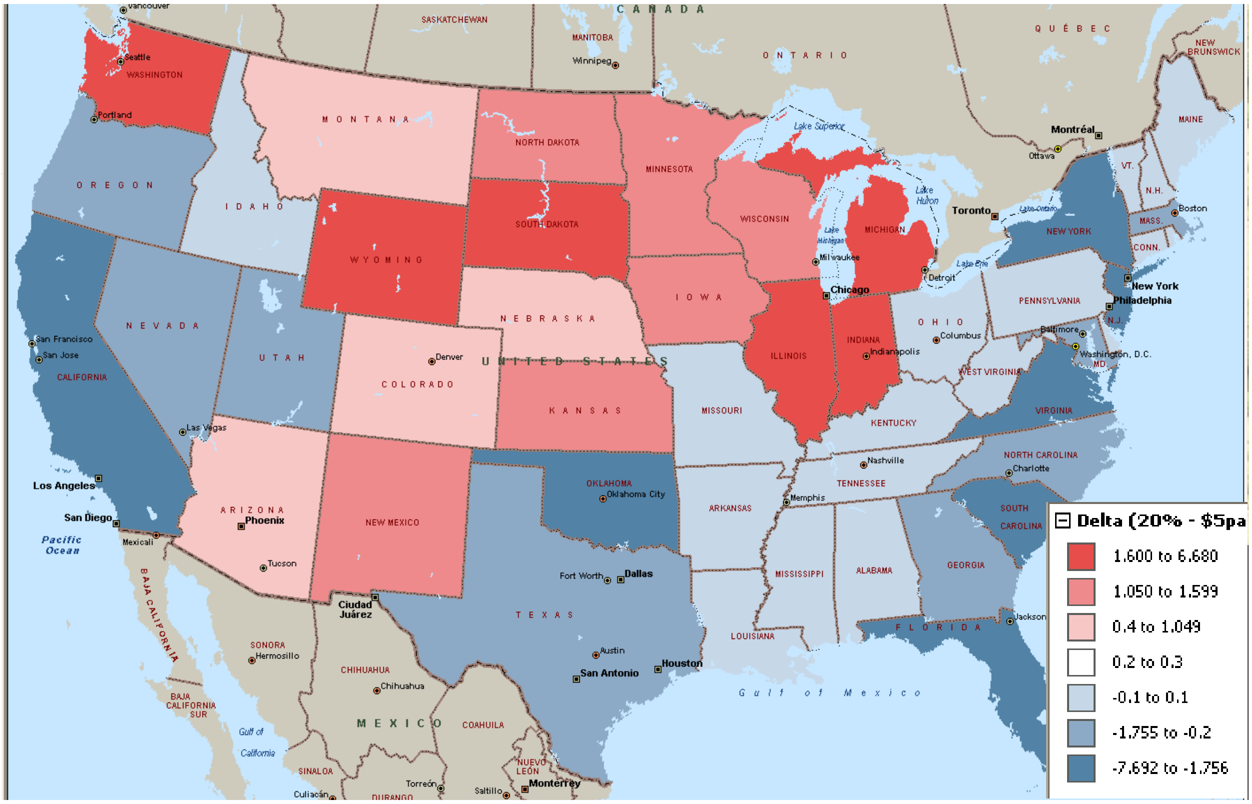


Figure 7. Change in 2030 state wind capacity levels when the pancake (wheeling) charge is increased to $5/MW-"PCA crossed"

6. Overall Sensitivity Results

Several individual sensitivities are discussed above. However, the aggregate result of the sensitivities also can yield several notable results. The overall impact of the sensitivities can help create a band of expected values that is useful to various wind industry stakeholders and is a step toward better understanding the uncertainty of the results in the 20% Wind Scenario report.

The first aggregate result is to examine the amount of wind deployed in each state across all sensitivities. Figure 8 maps the value of state wind capacity in 2030 averaged across all of the sensitivities. By comparing this to Figure 1, it is evident that states with the highest amount of deployment in the 20% Wind Scenario report have been moderated and states with very minimal levels have increased slightly.

Figure 8. Mean value of 2030 state wind capacity (GW) across all sensitivities

Likewise, Figure 9 maps the maximum value of 2030 wind capacity across all sensitivities. This illustrates that most states achieve some level of wind penetration in at least one or more of the sensitivity runs.

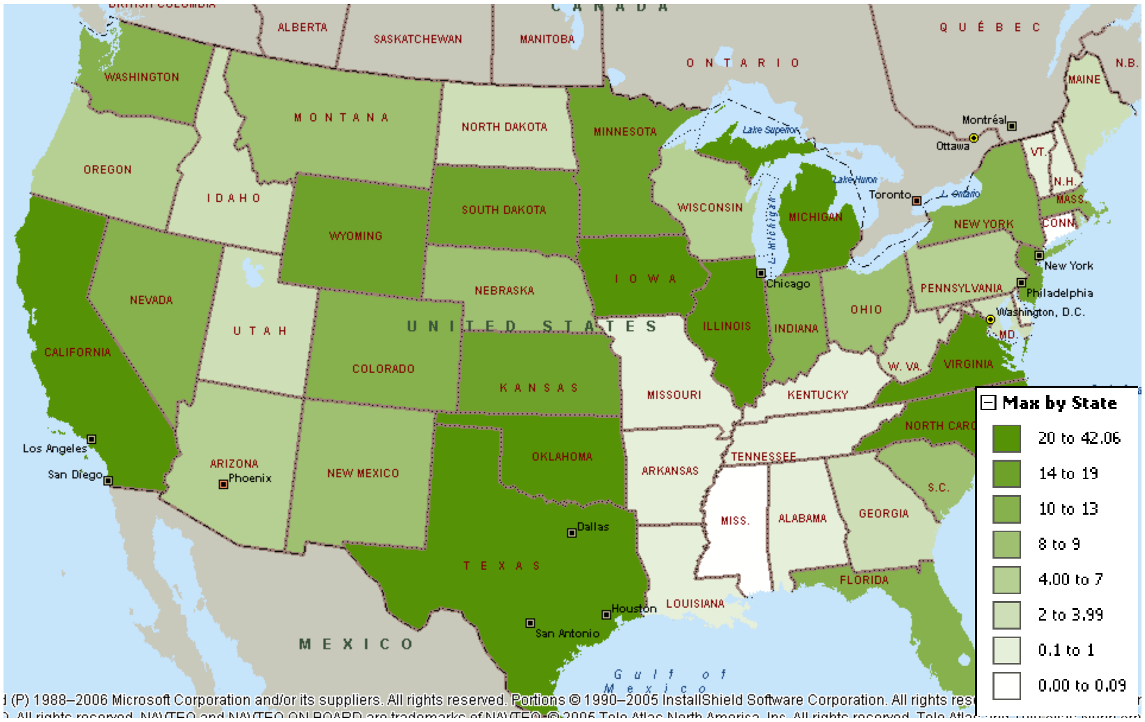


Figure 9. Maximum value of 2030 state wind capacity (GW) across all sensitivities

Finally, Figure 10 presents this data in a more quantitative way plotting, for each state, the very maximum value across sensitivities. The red bar indicates the mean value plus/minus one standard deviation, and the line extending from the bottom indicates the minimum value for all sensitivities. This data also indicates a broad spread is possible in some states and that almost all states have the non-zero maximum value.

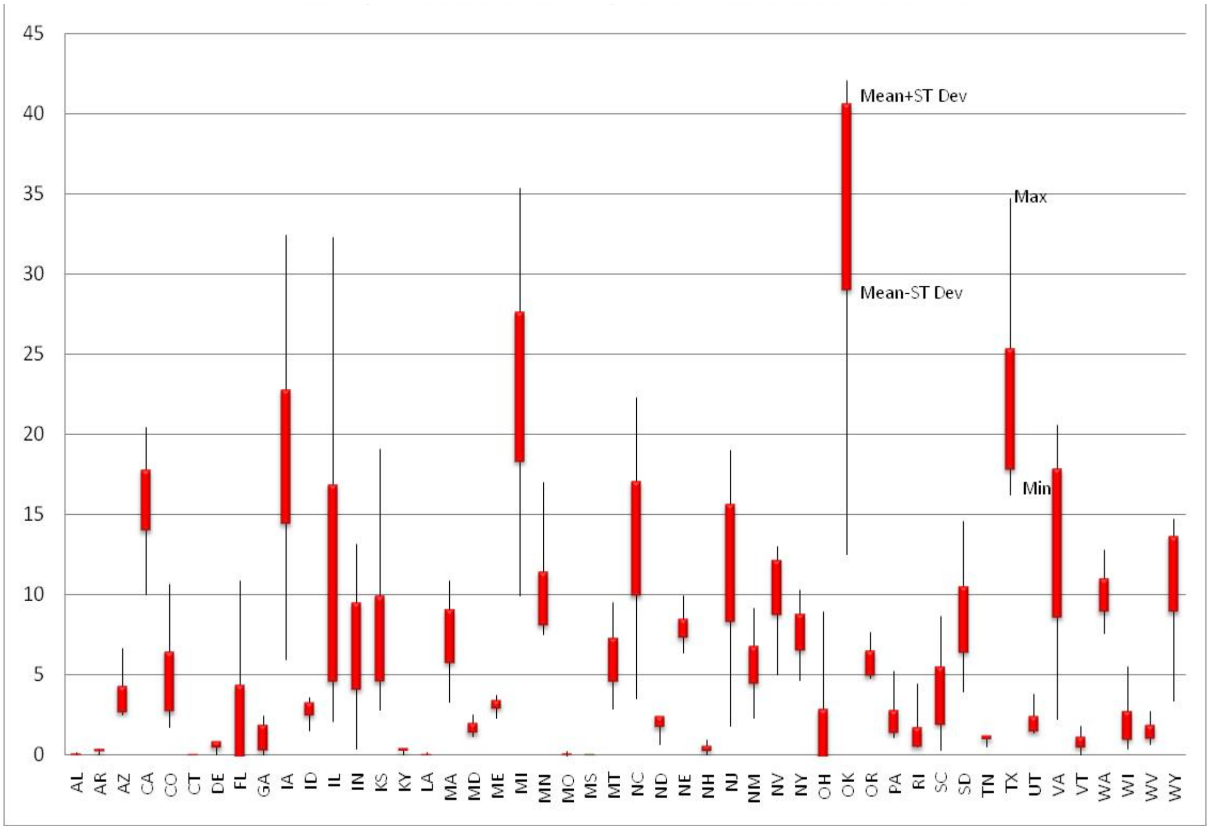


Figure 10. Max, Min, Mean, and standard deviation of 2030 wind capacity (GW) for all states across all sensitivities

Figure 11 illustrates the overall 2030 capacity mix for the entire country. As shown, most of the sensitivities have almost no impact on the distribution of capacity by contributor. Sensitivity 6 (sixth bar from the left) shows a much larger amount of unscrubbed coal plant capacity than is typical. This is because the SO_2 cap has been removed. Also singled out in a circle are the two sensitivities with either a 20% higher load growth rate or a 20% lower load growth rate, resulting in a noticeable difference in total capacity.

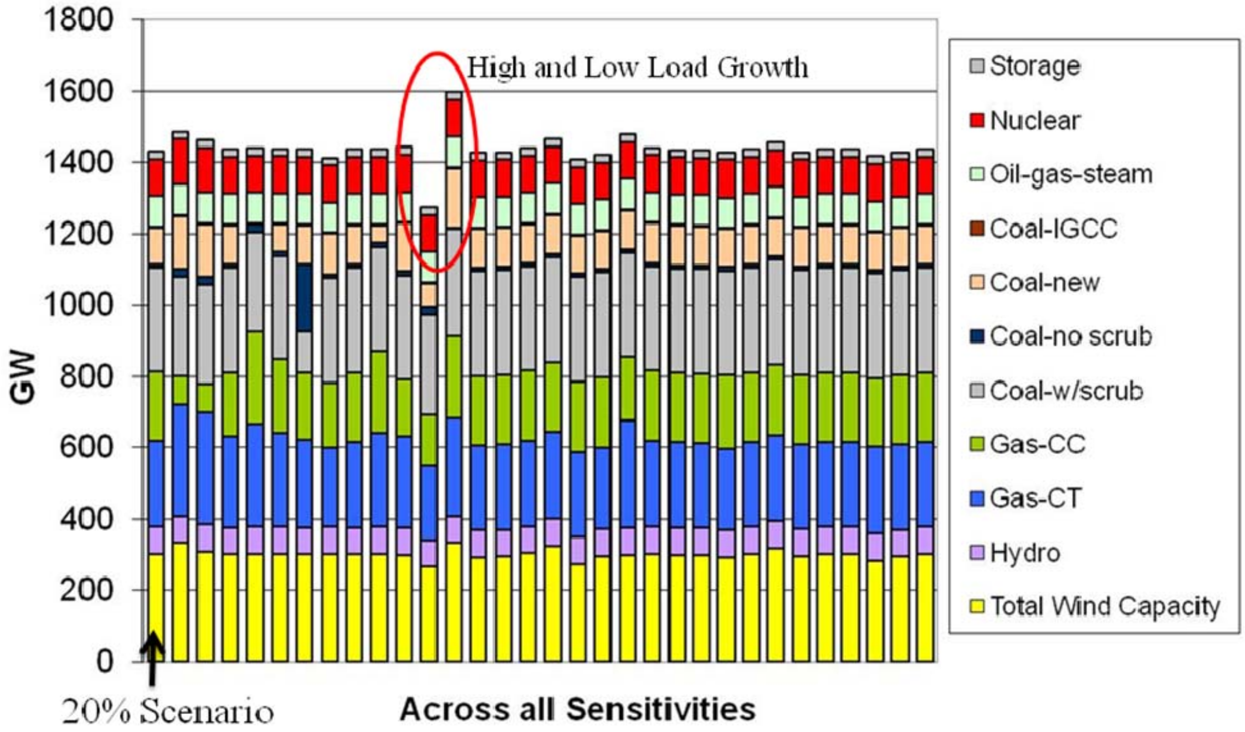


Figure 11. 2030 national capacity mix for all sensitivities

As shown for individual family results, the additional cost of reaching 20% wind generation is a key output of the 20% Wind Scenario report and can be viewed across all sensitivities (Figure 12). First, note that the majority of sensitivities show a minimal deviation from the original 20% Wind Scenario cost (shown in red on the left). However, there are several sensitivities that significantly increase the cost. Specifically (from left to right), they are using the EIA cost set, the AEO low fuel prices, 20% lower conventional capital costs, and no wind technology improvement. These sensitivities seem somewhat less likely to occur based on today's fuel and technology prices and trends, so it would seem less likely that the cost of reaching 20% wind generation would increase.

There also are several sensitivities that significantly reduce the cost of reaching 20% wind generation. Specifically (from left to right), these are using the DOE program goal cost set and having 20% higher improvements in wind capacity factor (high technology improvements).

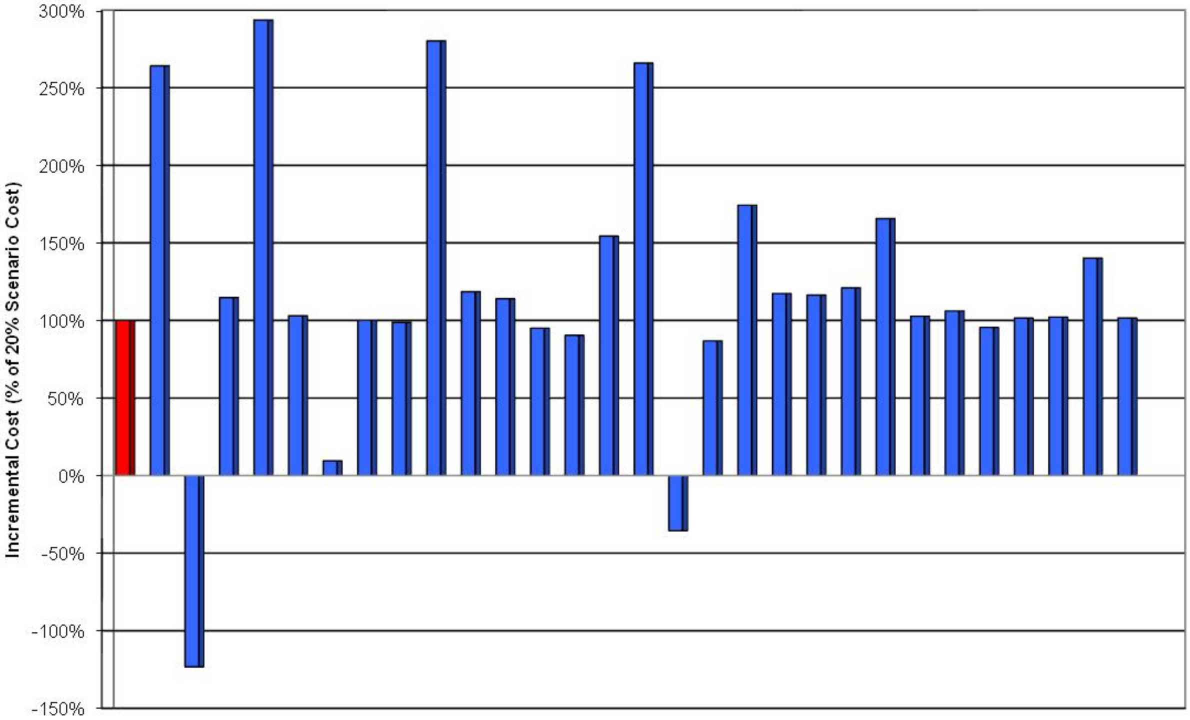


Figure 12. Net present value of the additional cost of achieving 20% wind generation in 2030 across all sensitivities compared to the actual 20% Wind Scenario

7. Conclusions

This array of sensitivities to the 20% Wind Scenario report resulted in several conclusions. First, every cost or assumption within the model can impact the final distribution and type of wind to some degree. The total capacity of wind by state varies significantly across the range of sensitivities, especially for states with a high level of wind penetration in the 20% Wind Scenario. As assumptions and inputs to the model are refined going forward, ReEDS (formerly WinDS) will need to measure the degree to which a sensitivity impacts the wind location. For example, a high pancake or wheeling cost significantly pushes wind toward the coasts and away from the Midwest. Also, a higher population density cost adder pushes more wind offshore from onshore (in high population-density zones).

The incremental cost of producing 20% of the nation's projected electricity demand from wind by 2030 is a primary metric from the 20% Wind Scenario report and was examined in this paper. Most parameter variations do not significantly affect the incremental cost of the 20% Wind Scenario. However, it does increase with no wind technology improvement, low conventional power costs, or low fuel prices. These sensitivities are not seen to be particularly realistic given today's energy climate. The incremental cost decreases with high wind technology improvements.

Additionally, the rate of change of the transmission and wind industries to respond to the scenario also impacts the incremental cost. Fast industry growth resulting in lower costs will reduce the overall cost of reaching the 20% wind-generation level. Obviously, slow response by industry will leave costs higher and result in a higher cost to reach the 20% level.

Finally, across all these variations on the original scenario, the basic outcome of the 20% Wind Scenario is still viable: Reaching 20% generation from wind is achievable without undue cost or limitations.

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[i] DOE EERE, "20% Wind by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply," DOE/GO-102008-2567, May 2008

[ii] O'Connell, et al. "20 Percent Wind Energy Penetration in the United States," http://www.20percentwind.org/Black_Veatch_20_Percent_Report.pdf,

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13. **SUPPLEMENTARY NOTES**

14. **ABSTRACT** *(Maximum 200 Words)*

In May 2008, DOE published “20% Wind Energy by 2030," a report that describes the costs and benefits of producing 20% of the nation’s projected electricity demand in 2030 from wind technology. The total electricity system cost resulting from this scenario was modestly higher than a scenario in which no additional wind was installed after 2006. NREL’s Wind Deployment System (WinDS) model was used to support this analysis. With its 358 regions, explicit treatment of transmission expansion, onshore siting considerations, shallow- and deep-water wind resources, 2030 outlook, explicit financing assumptions, endogenous learning, and stochastic treatment of wind resource variability, WinDS is unique in the level of detail it can bring to this analysis. For the 20% Wind Energy by 2030 analysis, the group chose various model structures (such as the ability to wheel power within an interconnect), and the wind industry agreed on a variety of model inputs (such as the cost of transmission or new wind turbines). For this paper, the analysis examined the sensitivity of the results to variations in those input values and model structure choices. These included wind cost and performance improvements over time, seasonal/diurnal wind resource variations, transmission access and costs, siting costs, conventional fuel cost trajectories, and conventional capital costs.

15. **SUBJECT TERMS**

NREL; wind energy; 20% by 2030; Wind Deployment System model; WinDS; transmission cost; wind turbines; modeling sensitivities; wind scenario; siting costs; Nate Blair; Maureen Hand; Walter Short; Patrick Sullivan

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