Using Probability of Exceedance to Compare the Resource Risk of Renewable and Gas-Fired Generation

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What is "resource risk"?

<u>Resource risk</u>: The risk that the underlying energy resource that is harnessed to generate electricity will not be as plentiful as expected, or will cost more than expected.

Resource risk manifests differently for renewable and gas-fired generation:

- **For renewable generators like wind and solar projects:** Resource risk is primarily a ***quantity*** risk—i.e., the risk that the quantity of wind and insolation will be less than expected.
  - Over shorter time periods there can also be a temporal aspect to wind and solar resource risk—e.g., whether the wind will be blowing (or the sun shining) at times of high system demand and prices—but this report focuses on longer time frames (measured in years rather than in minutes, hours, days, or months), where quantity is the primary risk.
- **For a combined-cycle gas turbine (or "CCGT"):** Resource risk is primarily a ***price*** risk—i.e., the risk that natural gas will cost more than expected.

Who bears resource risk?

	Risk of High Gas Prices		Risk of Low Solar/Wind Output	
Stakeholder	Utility-Owned CCGT	IPP-Owned CCGT	Utility-Owned Solar/Wind Plant	IPP-Owned Solar/Wind Plant
Independent Power Producers (IPPs)	None	None/ Low	None	Moderate/ High
Utility Ratepayers	High	High	Moderate	Moderate/ Low
Utility Shareholders	Low	Low	Low	Low

- Resource risk falls disproportionately on ratepayers (or "customers" more broadly in a deregulated setting)
- In general, higher-than-expected gas prices appear to be riskier (to ratepayers) than lower-than-expected wind or solar output
- As such, it is incumbent upon utilities, regulators, and policymakers to ensure that resource risk—and in particular natural gas price risk—is taken into consideration when making or approving resource decisions

Wind and solar's ability to "hedge" natural gas price risk clearly motivates buyers

Utility offtakers:

- "This solar energy center adds diversity to WPPI Energy's power supply portfolio in a way that's more cost-effective than other opportunities currently available to us." *– WPPI Energy, 2017*
- "When we're buying wind at $25, it's a hedge against natural gas." *– Xcel Energy, 2015*
- "We like wind because it's a hedge against fossil prices…and wind, with no fuel costs associated, can keep those rates stable." *– MidAmerican Energy, 2015*
- "The latest addition of 150 megawatts of low-cost wind energy provides AECC with a hedge against fluctuating natural gas energy prices." *– Arkansas Electric Cooperative Corp, 2013*
- "We think of this wind contract as an alternative fuel, with known contract pricing over 25 years that will displace fuels where the pricing is not yet known. That is the essence of the fuel hedge" *– PSCo, 2012*
- "[Wind PPAs] decrease our exposure to natural gas, provide a hedge against any future global warming legislation, and help us give our customers lower, more stable prices." *– Empire District Electric Company, 2008*
- "Wind generation provides value simply for the insurance it furnishes in insulating customers from some of the aspects of unexpectedly high and volatile fuel and wholesale energy prices." *– Westar Energy, 2007*

Corporate offtakers:

- "Investing in large-scale renewable power…helps Lockheed Martin hedge against the volatility of the electricity market and lower our energy costs…This is a nice addition to our current hedging strategy…This gives us the ability to hedge out in a different way, for a much longer term." *– Lockheed Martin, 2016*
- "Electricity costs are one of the largest components of our operating expenses at our data centers, and having a long-term stable cost of renewable power provides protection against price swings in energy." *– Google, 2016*
- "Cost savings are the main driver, but price stability is a close second." *– General Motors, 2013*
- "We see value in getting a long-term embedded hedge. We want to lock in the current electricity price for 20 years. We are making capital investment decisions on the order of 15 to 20 years. We would like to lock in our costs over the same period." *– Google, 2011*

But what is this “gas price hedge” worth? How do you even quantify it?

Existing approaches can be unwieldy and not entirely satisfying:

1) Mean-variance portfolio theory (efficient frontiers) and risk-adjusted discount rates
   - Both rely on the financial sector’s Capital Asset Pricing Model (CAPM), which may not be entirely applicable to the energy sector
   - Both rely on gas having a “negative beta” – which can be tricky to measure (e.g., is the correlate the stock market or the broader economy?) and can change over time
2) Diversity indices
   - Can tell how diverse your portfolio is, but not how to value that diversity or what it’s worth
3) Decision analysis/certainty equivalence
   - Do you know the appropriate utility functions or risk-aversion coefficients?
4) Scenario analysis, sensitivity analysis, Monte Carlo simulations
   - Have you chosen the right scenarios and/or distributions to model? Have some been weeded out too early through prior screens? Are you capturing all possible inter-linkages?
5) Market-based assessments of the cost of hedging gas price risk
   - But some academics will argue that hedging is “costless”
   - Alternative means of hedging gas price risk are typically short-term, and seldom extend beyond 10 years (temporal mismatch with 20+-year wind/solar PPAs)

New approach focuses on worse-than-expected outcomes using “probability of exceedance” levels

“Probability of exceedance” levels are commonly used in the wind and solar industries to describe the wind and solar resource at a particular site

- Resource analysts typically calculate P50, P75, P90, P95, and P99 generation projections over different time horizons (1 year, 10 years)
  - P50 (median or expected): There is a 50% chance that actual production will be either higher or lower than the P50 generation estimate
  - P99 (worst-case): There is a 99% chance that actual production will exceed the P99 estimate during the period in question (e.g., 1 year, 10 years)
  - P99 < P50 generation due to uncertainty in wind/solar resource estimate
  - Gap between P99 and P50 narrows over longer time horizons, as random inter-annual variability tends to “cancel out” over time
- Different stakeholders involved with a project will be interested in different P-levels (e.g., P50 vs. P99), and calculated over different time horizons (e.g., 1 year vs. 10 years)

Probability of exceedance is based on uncertainty surrounding annual energy production (AEP)

Equation 1: Total uncertainty$_{\text{AEP}}$ = $\sigma_T = \sqrt{\sigma_a^2 + \left(\sigma_b/\sqrt{\#\ years}\right)^2 + \sigma_c^2}$

Where:

- σ_T = total uncertainty surrounding annual energy production ("AEP")
- σ_a = measurement uncertainty (systematic error)
- σ_b = inter-annual variability (random error)
- σ_c = production modeling uncertainty (systematic error)

- Because inter-annual variability in the wind or solar resource (σ_b) is considered to be random and normally distributed about the mean, it tends to cancel out somewhat over longer time periods, decaying at the rate of $1/\sqrt{\#\ years}$
- As a result, the total AEP uncertainty also decreases over longer time horizons (even though the other two error terms$-\sigma_a$ and σ_c $-$are considered to be systematic, and so do not decay over time)

Total AEP uncertainty estimates for wind and solar

			Solar				Wind	
			B&V	AWS	**LBNL**		AWS	**LBNL**
σ_a	measurement uncertainty		5-10%	2.1-15.2%	**7%**			
σ_b	inter-annual variability		2-6%	2-5%	**4%**			**7.9%**
σ_c	production modeling uncertainty		3.5%	3.1-5.5%	**3.5%**			
σ_T	Total AEP uncertainty (from Equation 1)	1 year	6.4-12.2%	4.2-16.9%	**8.79%**			**11.24%**
		10 years	6.1-10.8%	3.8-16.2%	**7.93%**		5.1-14.6%	**8.41%**
		25 years	6.1-10.7%	3.7-16.2%	**7.87%**			**8.18%**

- Uncertainty is expressed as the "coefficient of variation"—i.e., the standard deviation divided by the mean
- LBNL solar values are chosen to be roughly in the middle of the indicative ranges provided by Black & Veatch (B&V) and AWS Truepower (AWS)
- LBNL wind values are derived from an actual wind project operating in Oklahoma (with inter-annual variation of 7.9% and *total* systematic error of 8.1%—i.e., could not break down systematic error into its two components σ_a and σ_c)
- These are for *pre-construction* estimates for *individual* projects; uncertainty can be reduced by conducting *operational* energy assessments (once projects are operational) and by looking across a *portfolio* of diverse projects (see text box on page 36 of report)

Probability of exceedance around the P50

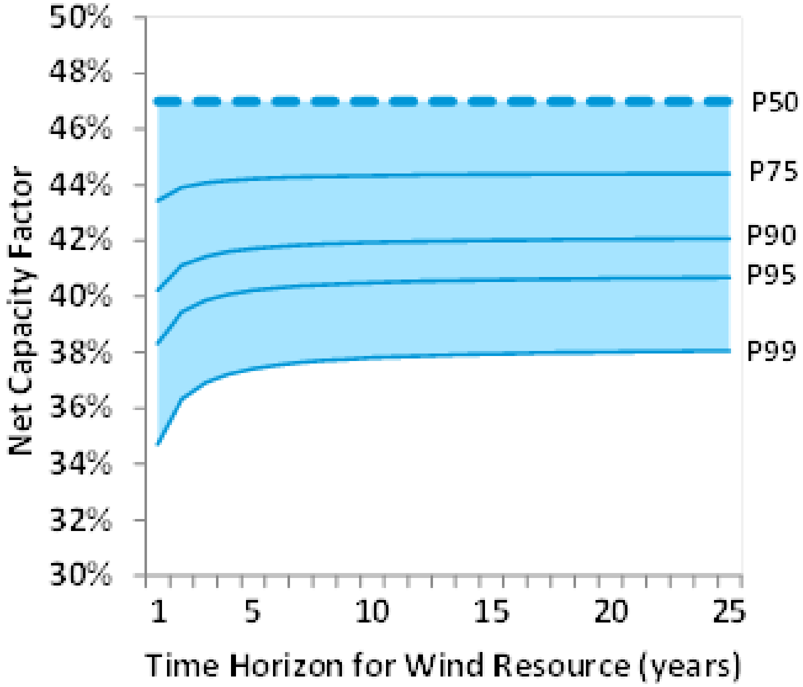
Equation 2: $P_\alpha = P_{50} * [1 - (z_{\alpha,\infty} * \sigma_T)]$

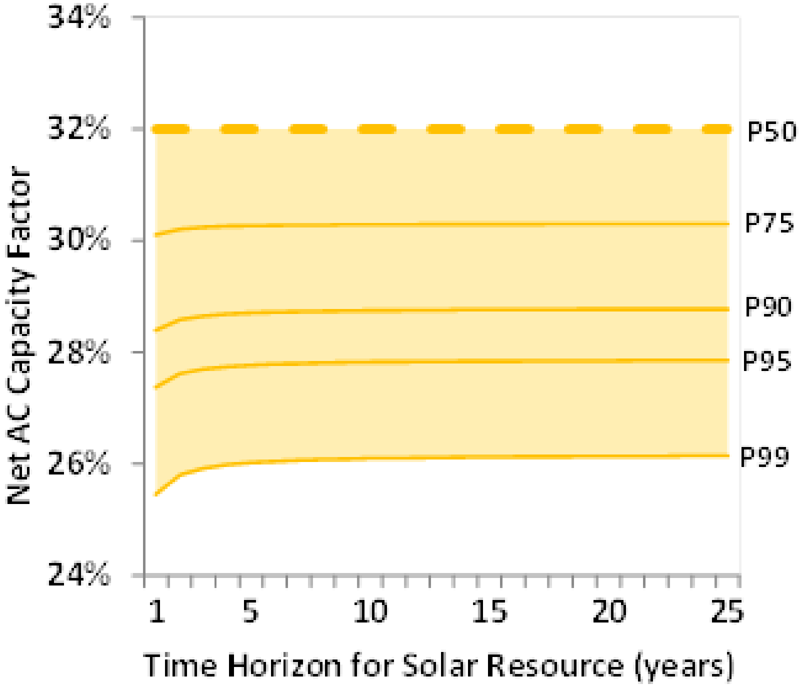
Where:

- $P_\alpha =$ Desired probability of exceedance level (other than P50)
- P_{50} = P50 annual energy production estimate
- $z_{\alpha,\infty}$ = Standard normal distribution value for $(1 - \alpha)$ confidence level with infinite degrees of freedom
- σ_T = total uncertainty surrounding the central estimate of wind or solar generation (from Equation 1)

- Although Equation 2 implies a symmetrical distribution around the P50 projection, when dealing with annual energy production (AEP) there are technological limitations at the upper tail of the wind or solar resource distribution that cap the amount of incremental AEP resulting from a significantly stronger-than-expected wind or solar resource
  - A wind generator or solar inverter already operating at full capacity cannot generate more
  - Lower tail not similarly affected—which is one reason to focus on worse-than-expected AEP

Resulting P50-P99 wind and solar capacity factors

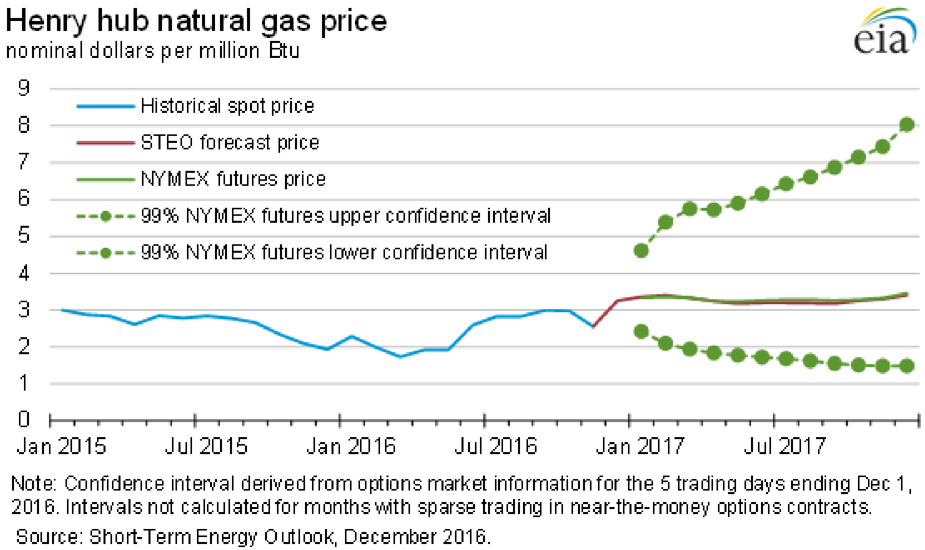




- P50 projections of 47% (wind) and 32% (solar) do not vary by time horizon
- All other P-levels—which are based on the total AEP uncertainties shown on slide 8—gravitate towards P50 over longer time horizons as random inter-annual variability cancels out
- Solar's P50-P99 range of capacity factors is narrower than wind's due to less AEP uncertainty, and there's also less upward drift towards P50 due to solar's lower inter-annual variability

What's the corollary for natural gas prices?

EIA's Short-Term Energy Outlook *provides some inspiration*



$$E(f_{\tau,k}) > f_{t,k} * \exp\left[-\left(z_{\alpha/2} * \sigma_k \sqrt{\tau_k}\right)\right]$$
$$E(f_{\tau,k}) < f_{t,k} * \exp\left[+\left(z_{\alpha/2} * \sigma_k \sqrt{\tau_k}\right)\right]$$

$E(f_{\tau,k})$ = Expected month k price at expiration date τ

$f_{t,k}$ = Month k futures price at day t

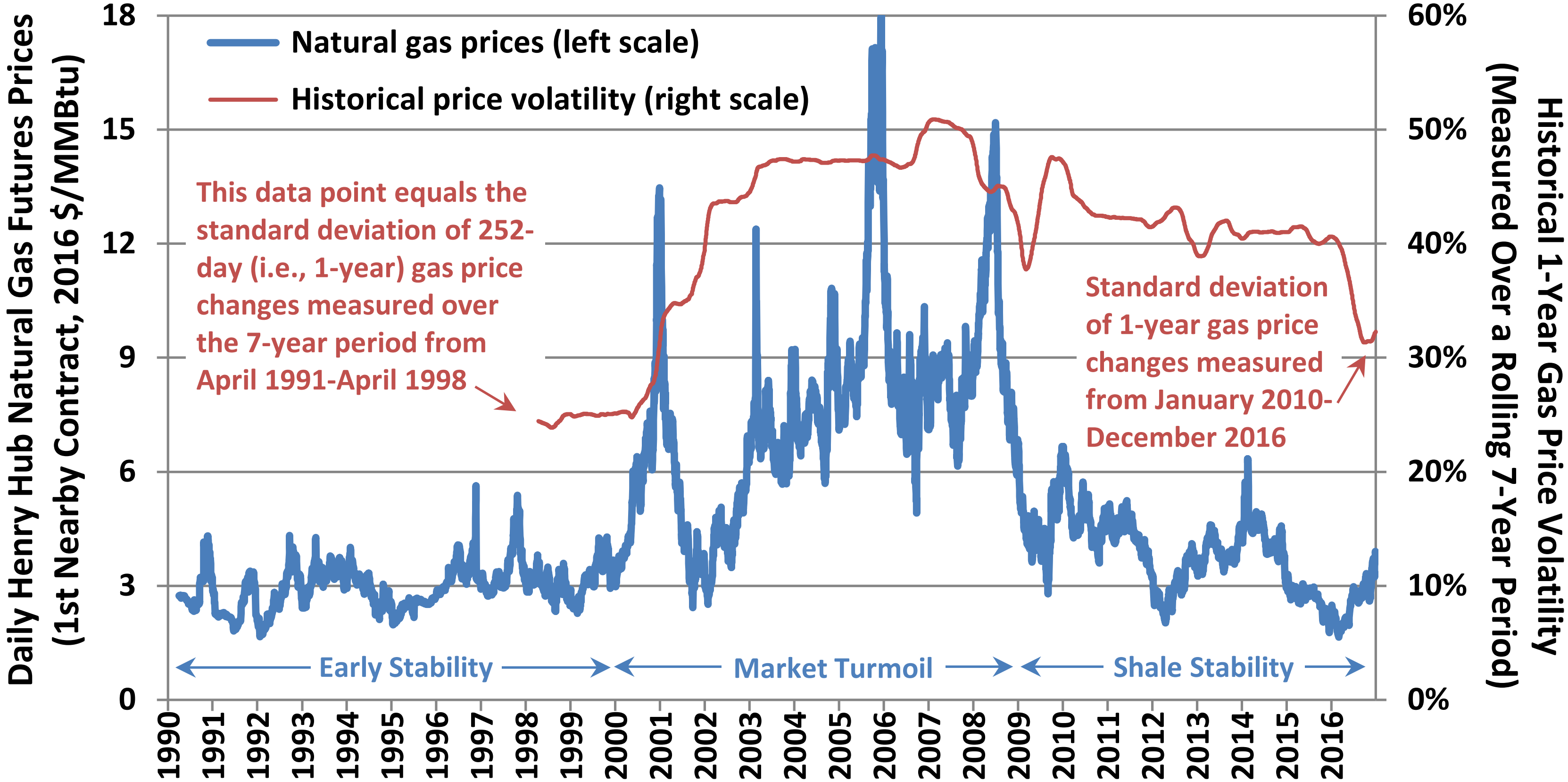
σ_k = Implied volatility for option on month k futures contract

τ_k = Time to expiration for month k futures contract (in years)

$z_{\alpha/2}$ = Standardized normal distribution value for (1-α) confidence level

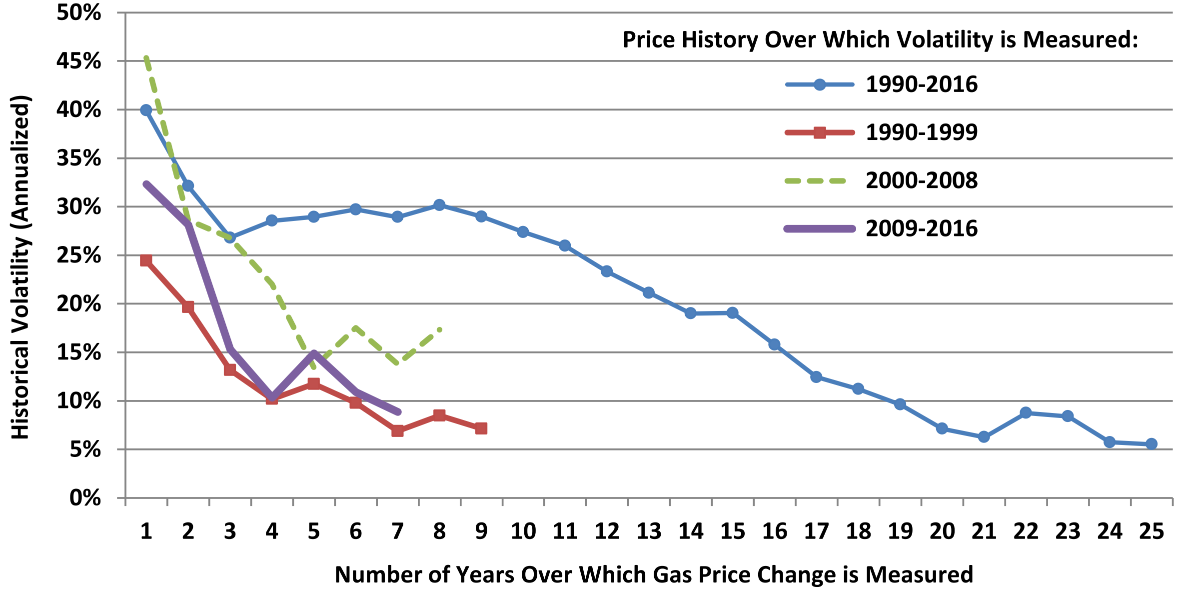
- Each month, EIA's *Short-Term Energy Outlook* presents confidence intervals around natural gas futures prices, derived from the price of options on those futures contracts:
  - ➢ Calculated by running the Black-Scholes option pricing model backwards – i.e., plug in the observed option price and pull out the implied volatility of the futures contract in question
  - ➢ Then plug that implied volatility into the equation above to generate confidence intervals
- But need to extend these short-term confidence intervals and projections out 25 years
  - ➢ By extending the implied volatility curve using a fitted decay curve that is benchmarked to historical volatility over various time horizons (see Slides 12 and 13)
  - ➢ By using the full 13-year futures strip, and extrapolating the final 12 years (see Slide 14)

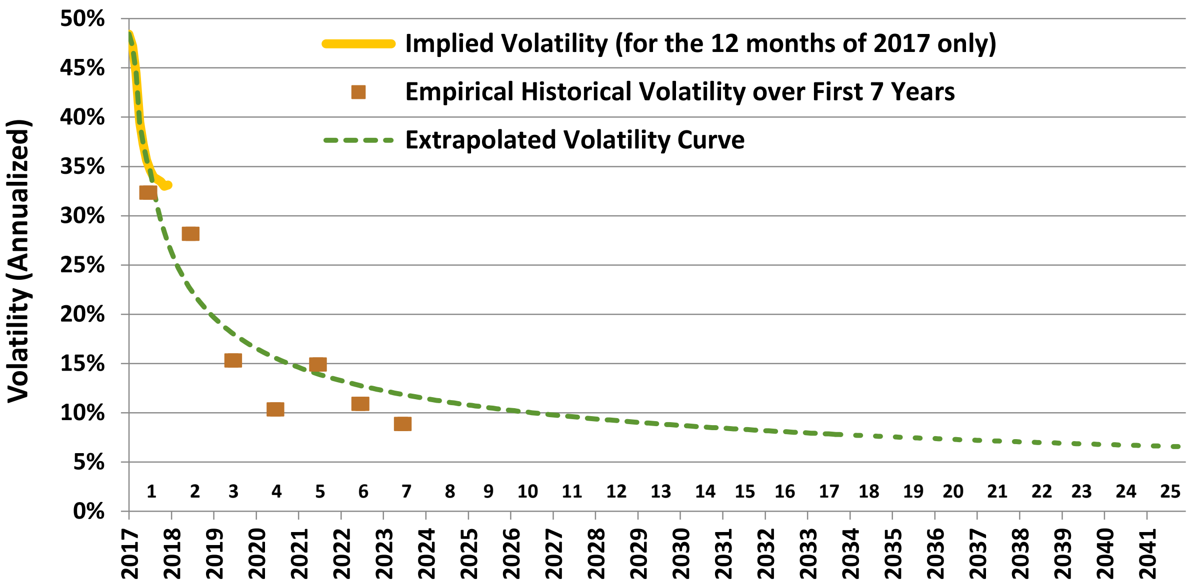
Implied volatility not calculable over long time horizons, so need to rely on historical volatility



- Three distinct pricing environments: low volatility in 1990s, turmoil in 2000s, shale stability since 2009
- Post-2008 shale price environment likely to be most representative going forward
- Historical 1-year volatility of 32.3% over this post-2008 period is below the 40-50% range seen for much of this century but above the ~25% volatility seen in the 1990s

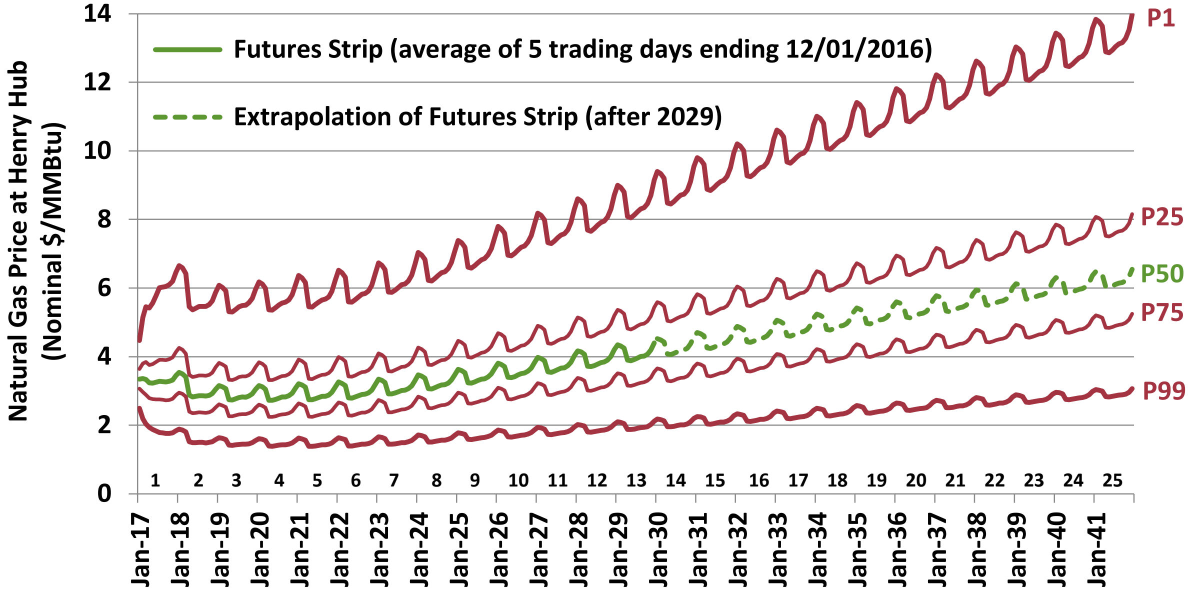
Annualized gas price volatility decays exponentially over longer time horizons

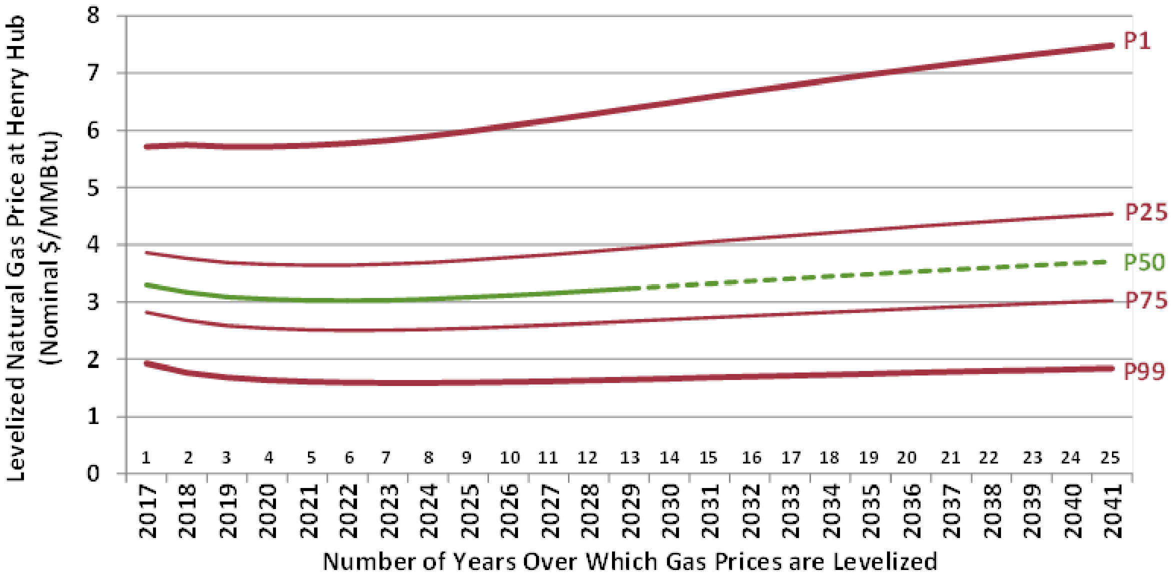




- Top graph shows historical volatility measured over different time horizons (1-25 years) and using different price histories (that represent the three distinct pricing periods noted on the previous slide, as well as the entire price history from 1990-2016)
- Purple line shows the post-2008 period used in this study: 1-year volatility of 32.3% declines when measured over longer time frames
- But empirical data from the post-2008 period only gets us 7 years, and we need 25
- Bottom graph extrapolates a 25-year volatility curve (dashed green line) from the post-2008 empirical data (the brown squares, which match the purple line in top graph)
  - ➢ n-year volatility = 1-year volatility/$\sqrt{n}$
  - ➢ Extrapolated curve closely approximates both implied and historical volatility

Resulting probabilistic gas price projections





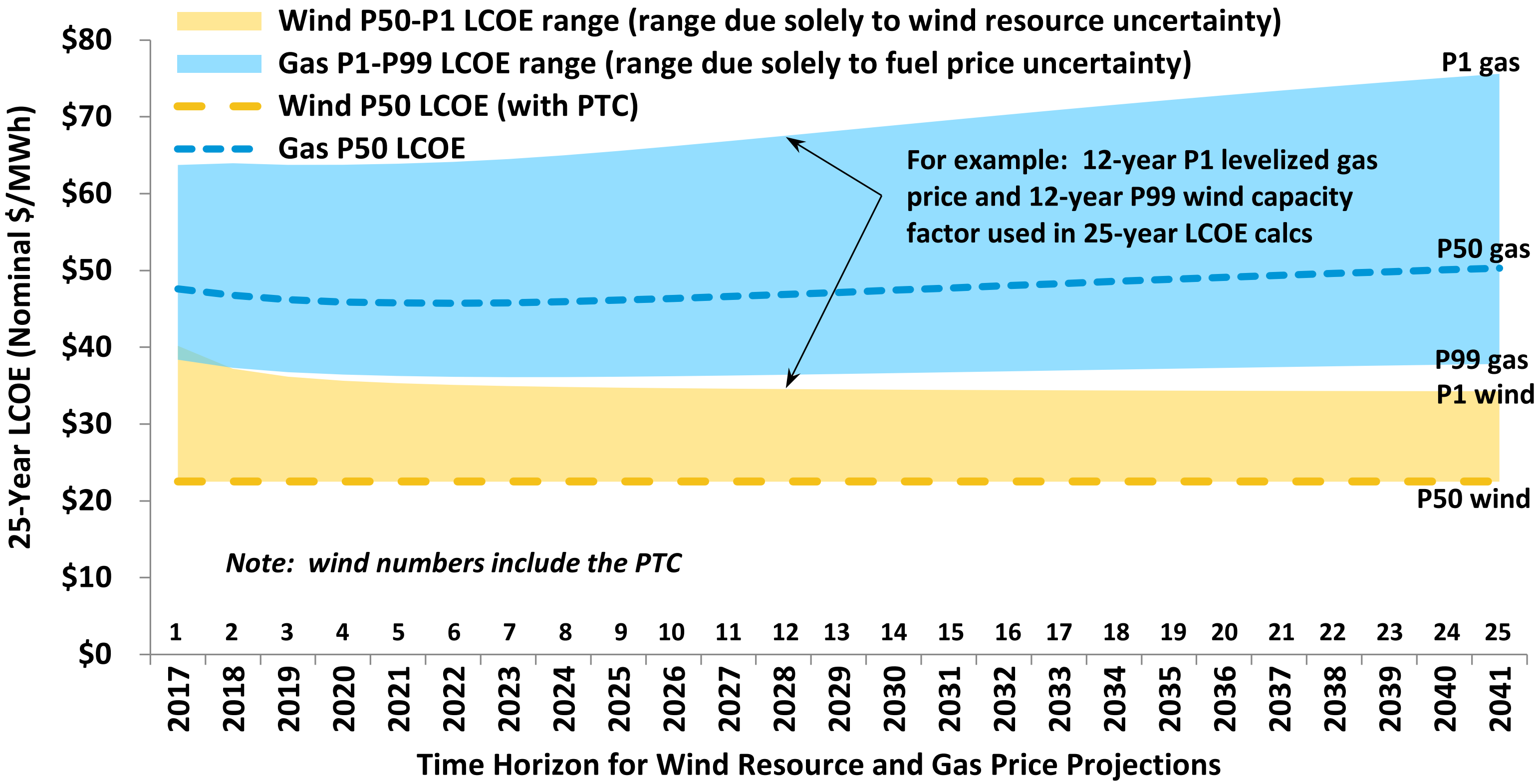
- Solid green curve shows the full natural gas futures strip through 2029; the dashed green curve extrapolates through 2041 at the 2028-2029 slope
  - ➢ P50 is a bit of a misnomer for this central projection, which is more of an average than a median
  - ➢ But this misused terminology does not affect methodology
- Red curves show P1-P99 range of gas price projections, based on extrapolated volatility curve from Slide 13 and confidence interval equations from Slide 11
  - ➢ Confidence interval equations on Slide 11 are two-tailed, but here I've converted the projections to one-tailed in order to match "probability of exceedance" terms
- Bottom graph levelizes the price curves from the top graph over a successive number of years ranging from 1 to 25—***these levelized curves are what are used in the LCOE calculations***

Other assumptions for wind, solar, and CCGT plants starting operations on January 1, 2017

	Wind	Solar	Gas (CCGT)
CapEx	$1.50/W-AC	$1.80/W-AC	$1.10/W-AC
Fixed Non-Fuel O&M	$40.0/kW-year	$15.0/kW-year	$6.0/kW-year
Variable Non-Fuel O&M	None		$3.0/MWh
Fuel Price (25-Yr Nominal Levelized)	N/A		$3.71/MMBtu (25-yr P50)
Heat Rate	N/A		6,700 Btu/kWh
Net Capacity Factor	47.0% (P50)	32.0% (P50)	75.0%
Degradation	None	0.4%/year	None
Tax Depreciation	5-year MACRS		20-year MACRS
Nominal Discount Rate (WACC)	8.0%		
Inflation	2.0%/year		
Tax Rate	35% federal, 7.7% state (40% combined)		
Modeled Plant Life	25 years		

- Only the green-shaded values change with each model run, depending on the P-level and time horizon
  - ➢ Wind and solar capacity factors at different P-levels and over different time horizons come from Slide 10
  - ➢ Levelized gas price projections at different P-levels and over different time horizons come from the lower graph on Slide 14
- All other variables are held constant for all model runs in order to isolate the impact of resource risk
  - ➢ This is clearly a simplifying assumption
  - ➢ For example, if natural gas prices increase, the CCGT capacity factor may decline as gas-fired generation becomes less competitive
  - ➢ For example, if a wind turbine regularly experiences a higher-than-expected capacity factor, its O&M costs may increase due to increased wear and tear

With the PTC, wind's worst-case LCOE is below the CCGT's best-case LCOE over all time horizons > 2 years

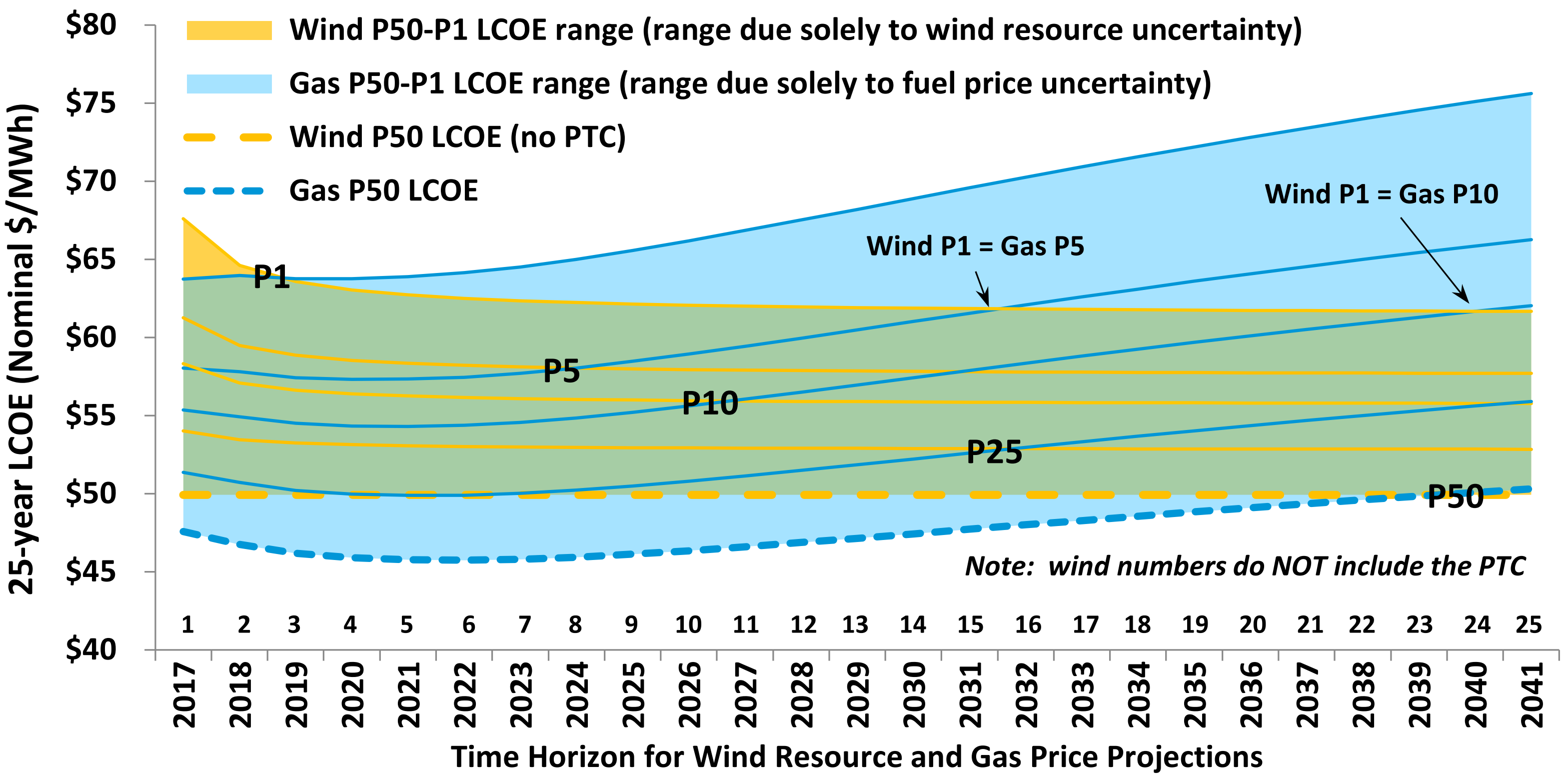


Note: Worst-case (P1) wind LCOE results from worst-case (P99) capacity factor from Slide 10, yet the lexicon of *probability of exceedance* requires that the higher-than-expected LCOE be re-labeled here as a P1, rather than a P99, LCOE

- LCOEs on graph are all over 25 years, but time horizon of uncertain inputs—i.e., wind capacity factors and levelized gas prices—varies along x-axis (*and* by P-level)
- For example, at year *n* on the x-axis:
  - **Wind:** *n*-year P50-P99 capacity factors are used in the 25-year LCOE calculation
  - **Gas:** *n*-year P1-P99 gas price forecasts are levelized (over *n* years) and used as the fuel price inputs in the 25-year LCOE calculation

Without the PTC, wind and gas LCOEs are more comparable

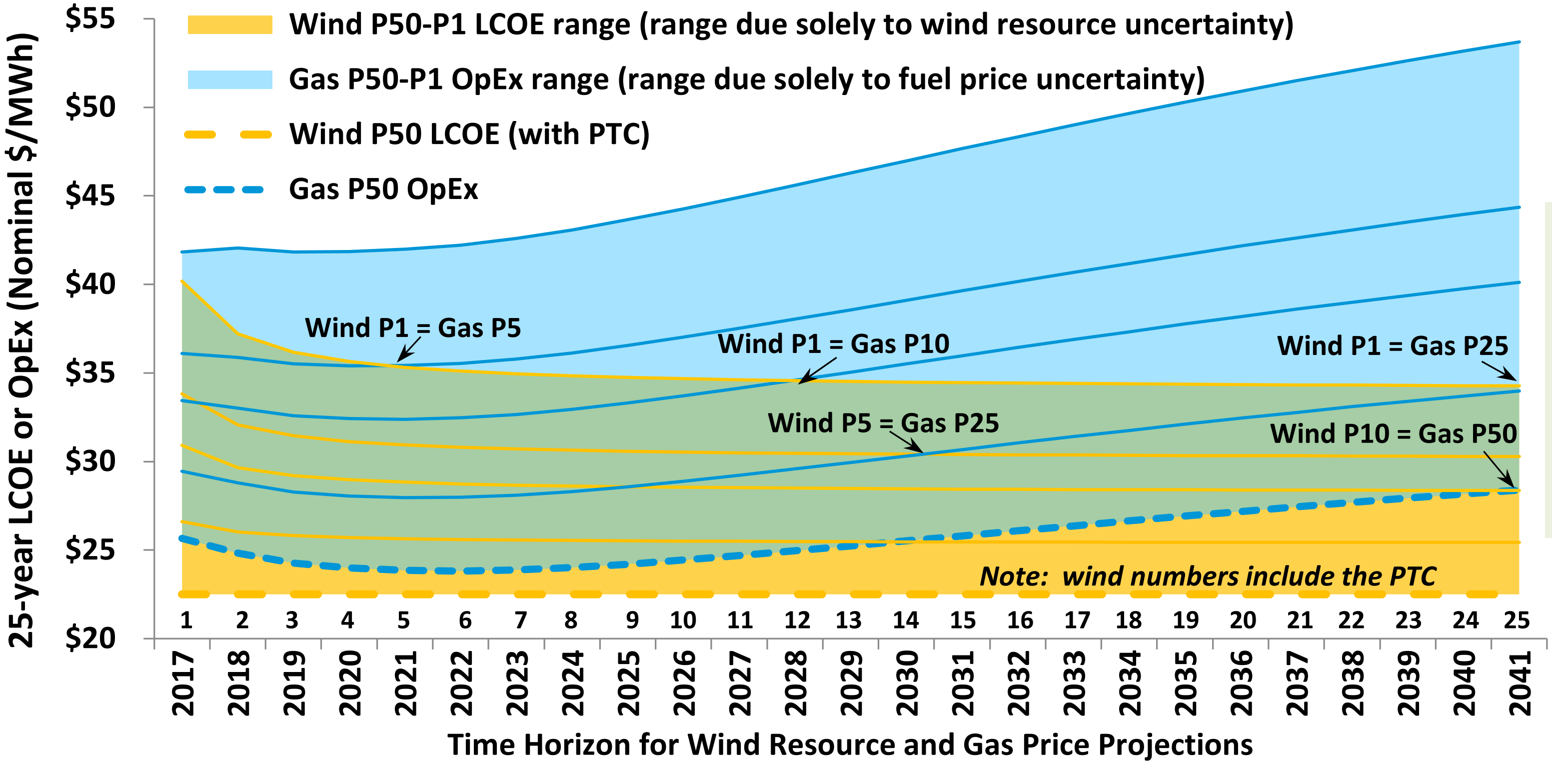
But moving beyond P50 outcomes favors wind over gas



In this comparison:

- Wind (without the PTC) is more expensive than gas on a P50 basis for all time horizons less than 24 years (i.e., the two P50 curves converge at 24 years)
- But on a P25 basis, wind costs less than gas over all time horizons >16 years
- This “break-even point” – where the wind and gas LCOE curves for each P-level cross – drops to 10, 8 and 2 years for P10, P5 and P1 levels, respectively

Wind (with the PTC) LCOE versus Gas-Fired OpEx

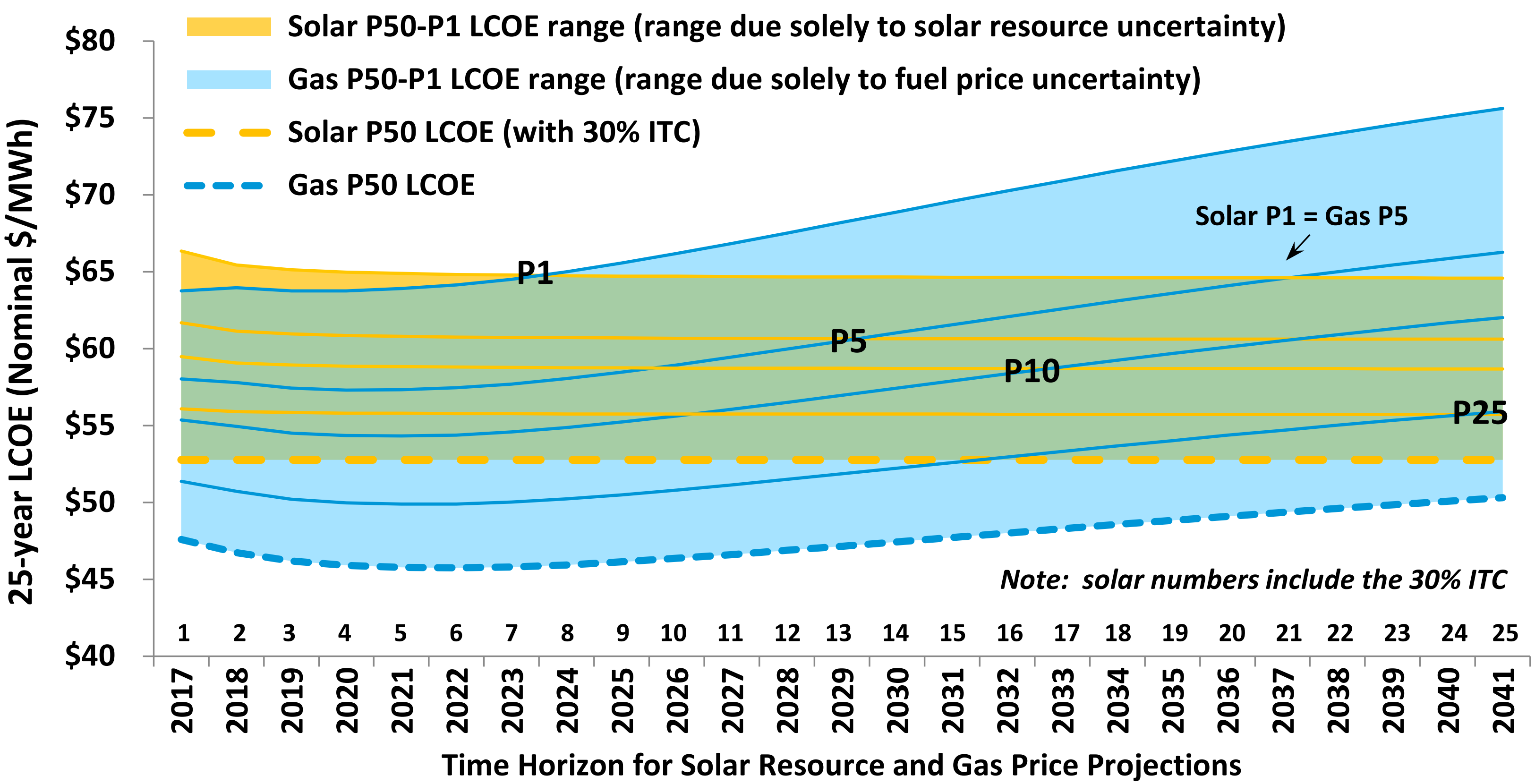


Note: The CCGT OpEx includes fuel and variable O&M costs, but NOT fixed O&M costs or CapEx recovery.

- Intended to reflect the present, whereby new wind generation still likely has access to the PTC (by meeting “start construction” deadlines) but is competing primarily against *existing* gas-fired generators at their marginal operating costs (“OpEx”)
- At each P-level, wind LCOE always below CCGT OpEx, regardless of time horizon
- Lower-probability wind is cheaper than higher-probability gas over various time horizons

Solar (with the 30% ITC) LCOE versus CCGT LCOE

Pick your preferred level of risk aversion and time horizon

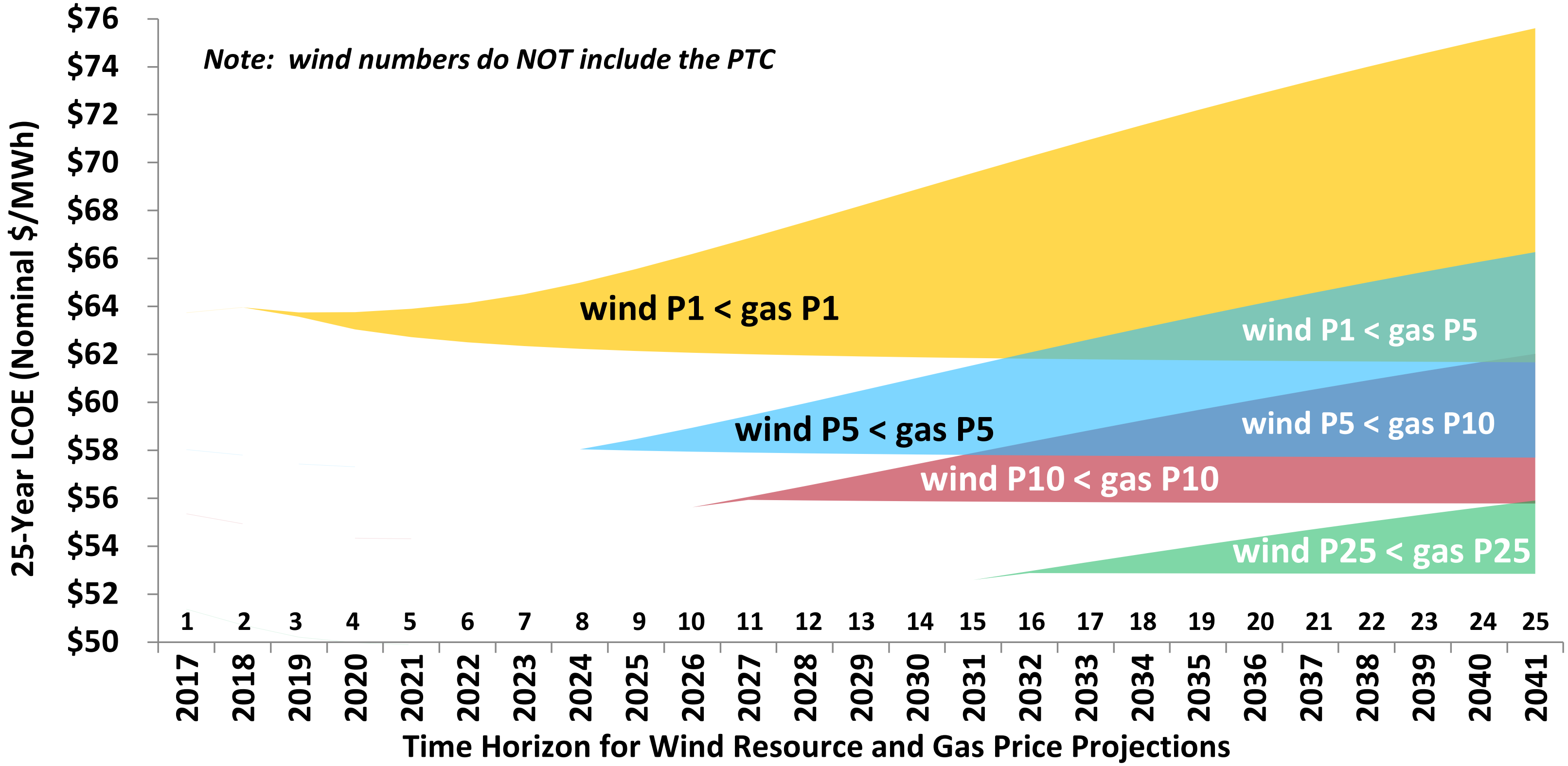


In this comparison:

- P50 solar (with the 30% ITC) is always more expensive than P50 gas, regardless of time horizon
- But on a P25 basis, both resources have the same LCOE over the full 25-year time horizon
- And even-more-risk-averse comparisons at lower P-levels show that solar can provide significant “hedge value”

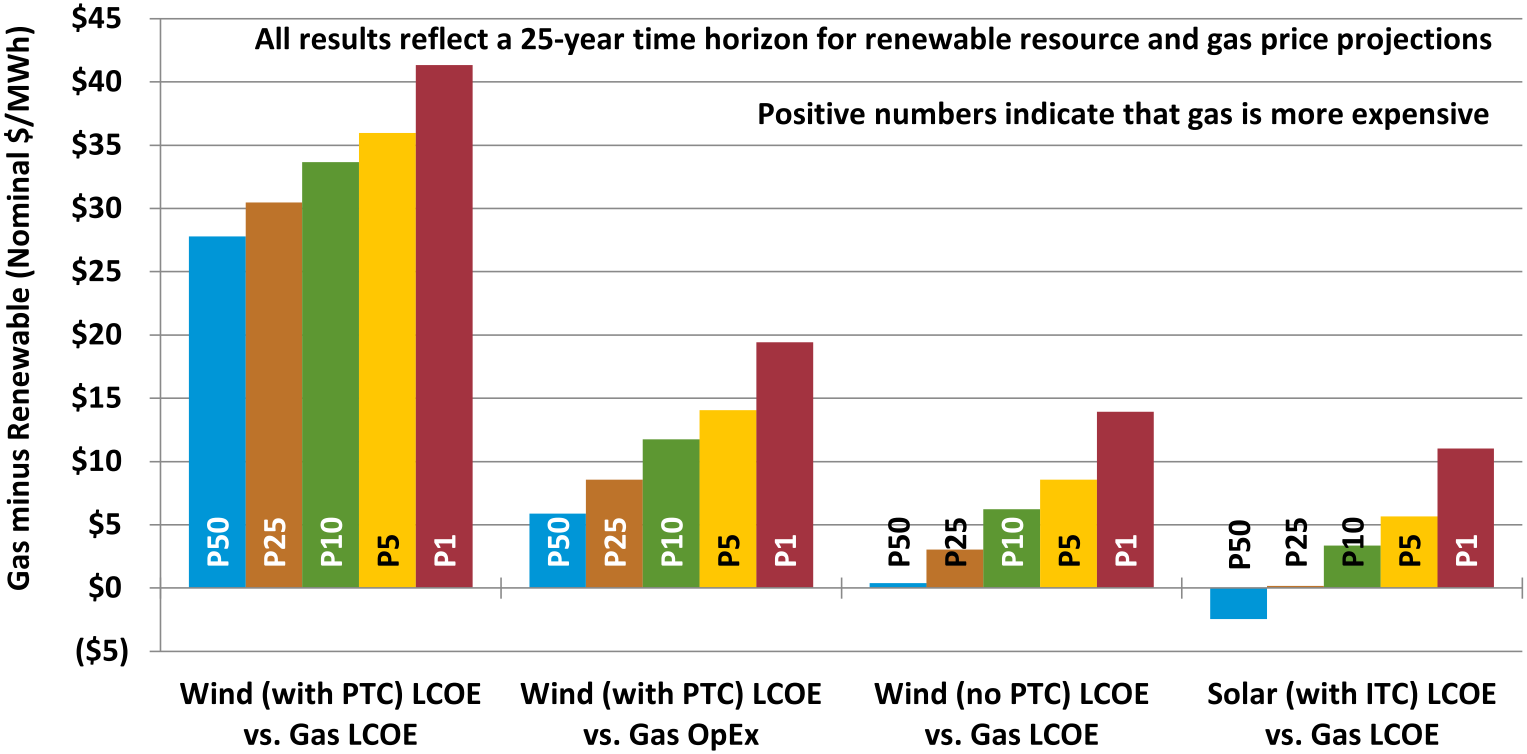
Visual representation of hedge value

(wind without the PTC vs. gas-fired LCOE)



- Each “hedge wedge” shows how much cheaper wind (without the PTC) is than gas over a range of time horizons and based on that particular P-level comparison
- The lower the P-level, the shorter the time horizon at which hedge value begins to accrue, and the greater the hedge value that exists over the full 25-year horizon

Consolidated results for 4 comparisons across 5 common P-levels and over 25-year time horizons



- Graph shows cost difference between CCGT and wind or solar; positive/higher numbers means that gas is more-expensive
- Although there is good reason to look at shorter time horizons (e.g., utilities may have a short-term need for energy, some investors are present for <10 years, ratepayers may have a short-term focus), most resource decisions will be made with a long (20- to 25-year) time horizon
- Moving beyond P50 favors wind and solar over gas-fired generation

Numerical results: At least 3 ways to account for resource risk within this framework

25-Year LCOE Difference (gas-wind) Nominal $/MWh	5 Years	10 Years	15 Years	20 Years	25 Years
Same P-Level Comparisons					
P50	-4.2	-3.6	-2.2	-0.8	0.4
P25	-3.2	-2.1	-0.3	1.5	3.1
P10	-1.9	-0.3	2.0	4.3	6.2
P5	-1.0	1.0	3.7	6.3	8.6
P1	1.2	4.1	7.7	11.1	13.9
Different P-Level Comparisons					
P10 gas – P1 wind	-8.4	-6.4	-4.0	-1.6	0.4
P5 gas – P1 wind	-5.4	-3.1	-0.3	2.3	4.6
P10 gas – P5 wind	-4.0	-2.3	0.1	2.4	4.3
P10 gas – P25 wind	1.2	2.7	5.0	7.2	9.2
Probability-Weighted Comparisons					
Some Negative Outcomes (P50-P25)	-3.8	-3.0	-1.5	0.1	1.4
All Negative Outcomes (P50-P1)	-3.5	-2.6	-0.9	0.8	2.2

Note: All comparisons pit new wind (without the PTC) against a new gas-fired CCGT on a 25-year LCOE basis, considering the wind resource and gas price projections over the five different time horizons and various P-levels shown.

1) Top of table: Comparing LCOEs at the same P-level over the desired time horizon
2) Middle of table: Comparing LCOEs across different P-levels over the desired time horizon
3) Bottom of table: Probability-weighting across a range of P-levels such as P50-P1, or perhaps P50-P25 if less risk averse (P50=50%, P49=49%...P2=2%, P1=1%)

Relative advantages of this framework

Fair	• Unlike other methods that assume renewables are "riskless" (de facto assuming only P50 outcomes), this approach recognizes that they also face resource risk (though in terms of quantity, not price)
Familiar	• Speaks a language – i.e., P50, P90 – that is well-known to energy analysts and policymakers alike
Simple	• Calculations require just a few accessible parameters: total energy uncertainty or P-table for wind and solar; price and volatility projections for gas
Flexible	• Caters to any level of risk aversion: from P51 to P99 • Caters to any time horizon: from 1 year to 25 years or longer
Intuitive	• Visual representations of hedge value are easy to grasp
Probabilistic	• Grounded in statistics; enables probability weighting

Big Caveat: Cost is only one aspect of the decision-making process—few if any resource decisions within the electricity sector are made solely on the basis of LCOE. Instead, the cost of competing resources must be considered along with the value that each provides, which is most often determined by sophisticated models that endogenously assess energy and capacity value as well as integration and transmission costs—all in addition to the LCOE of the generator itself.

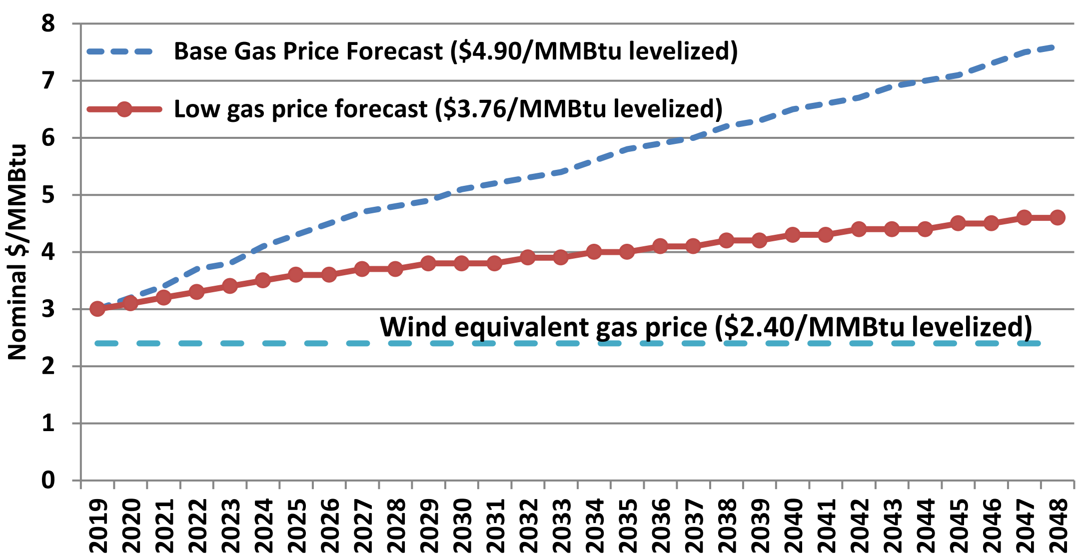
Parting Example: Southwestern Public Service (SPS) March 2017 announcement of 1,230 MW of new wind

SPS is procuring wind solely as a cost-saving measure:

- "SPS is proposing the Wind Resources solely as economic energy resources that can provide long-term low-cost energy that will offset more expensive existing generation and market purchases and net savings to SPS's customers."

The low-cost/fixed-cost wind power will displace a significant amount of natural gas at a low equivalent gas price:

- "…the Wind Resources would lock-in approximately 22 billion cubic feet of natural gas each year at a levelized gas price of approximately $2.40/MMBtu."
- "…22 billion cubic feet of natural gas represents approximately 20% of SPS's annual gas burn for electric production."



The locked-in equivalent gas price is well below even the low gas price forecast:

- "…the proposed Wind Resources will provide wind generation to the system that in essence locks in an equivalent gas price [of $2.40/MMBtu levelized] significantly below the low gas price forecast [of $3.76/MMBtu levelized]."

Thank you!

Download the full report at:

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Questions or comments? Send them to me at:

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