Wind Integration: Incremental Emissions from Back-Up Generation Cycling (Part I: A Framework and Calculator)

by Kent Hawkins
November 13, 2009

Editor note: Mr. Hawkins' study is presented to increase the interest in this highly important, politically sensitive issue of incremental pollution from firming up industrial wind power. This post has been joined by Parts II-V, with Part V providing updates to the calculator and links to the other posts.

Integrating random, highly variable wind energy into an electricity system presents substantial problems that subvert wind technology's ability to offset the use of fossil fuels–and avoid air emissions, including carbon dioxide (CO2). Measuring this accurately is important because many believe that wind projects significantly reduce such emissions.

This analysis finds that natural gas used as wind back-up in place of baseload or intermediate gas (in the absence of wind) results in approximately the same gas burn and an increase in related emissions, including CO2. Extrapolating from this example to the whole, the working hypothesis is that intermittent wind (and solar) are not effective CO2 mitigation strategies because of inefficiencies introduced by fast-ramping (inefficient) operation of gas turbines for firming otherwise intermittent and thus non-usable power.

Analysis

In the absence of extensive real-time load dispatch analyses at finely grained time intervals capable of accurately and sufficiently assessing all the variables affecting electricity system behavior as wind energy penetration increases, I propose a method – *a calculator* – that captures a wide range of considerations. I am unaware of any previous attempt that is as inclusive as what I present here and welcome reader comments for improvements on the present framework or alternative approaches.

This model, or calculator, provides a framework for the considerations involved and an interim assessment of their effects until sufficiently comprehensive studies can be performed in the areas indicated. It shows the impact on fossil fuel consumption and CO2 emissions compared to typical claims by wind proponents and other bodies, including some government policy makers. As it is parameter driven, the calculator allows examination of the sensitivity of these considerations. The result is that the typical claims are not supported, except by ignoring most of the following considerations:

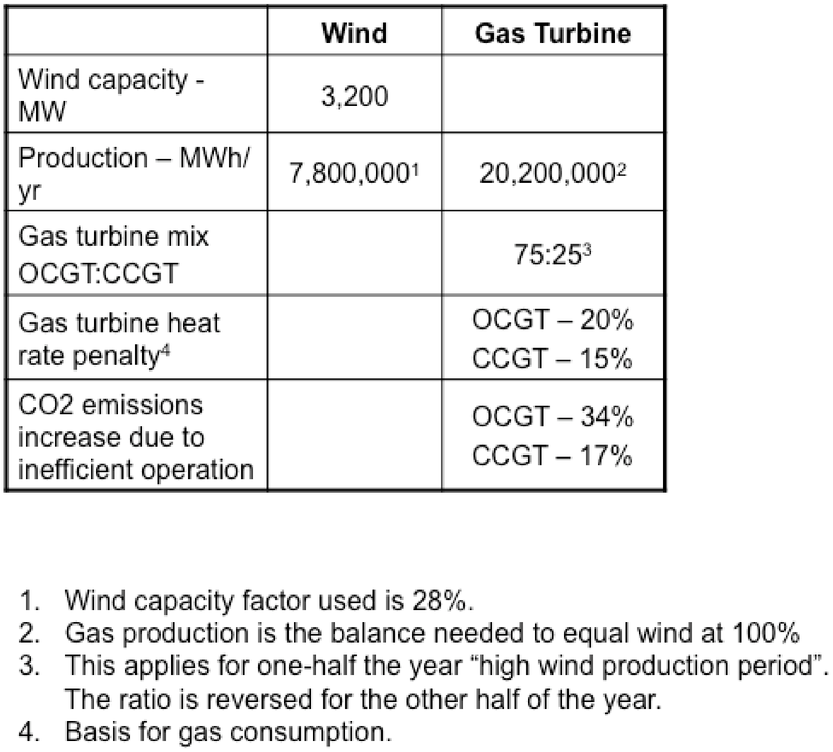
- The amount of wind mirroring/shadowing backup required.

- Inefficient operation imposed on the mirroring/shadowing backup, in terms of both the fossil fuel consumption and CO2 emissions, treated separately.
- The need to make comparisons, with respect to gas plants, of:
    - *Case A* – The more efficient Combined Cycle plants (CCGT) operating alone, in other words without the presence of wind, versus;
    - *Case B* – The appropriate mix of gas plant type used to balance wind's volatile output. This includes the need to introduce less efficient, but faster-reacting, Open Cycle Gas Turbine gas plants (OCGT) to mirror/shadow the wind production, especially as wind penetration increases.
- The effect of reduced wind capacity factor.
- The effect of wind output exceeding 1-2 percentage points of a total electricity system, on a country or regional basis.

The framework used is similar to that of **Warren Katzenstein and Jay Apt** (see citations below). It focuses on the wind/gas plant combination and has general applicability. Additional considerations involving wind's impact on other electricity system elements particular to a specific jurisdiction, such as baseload capacity as analyzed by Campbell, will have to be assessed separately and could have implications that further offset wind's claimed benefits.

Table 1 provides basic information on the wind and gas plants for the results contained in Figures 1 and 2.

Table 1 – Wind and Gas Plant Information



	Wind	Gas Turbine
Wind capacity - MW	3,200	
Production – MWh/ yr	7,800,000[1]	20,200,000[2]
Gas turbine mix OCGT:CCGT		75:25[3]
Gas turbine heat rate penalty[4]		OCGT – 20% CCGT – 15%
CO2 emissions increase due to inefficient operation		OCGT – 34% CCGT – 17%

1. Wind capacity factor used is 28%.
2. Gas production is the balance needed to equal wind at 100%
3. This applies for one-half the year "high wind production period". The ratio is reversed for the other half of the year.
4. Basis for gas consumption.

Figure 1 below displays the calculator results for fossil fuel savings. The “Typical Claim Scenario”, which ignores the heat rate penalties, shows over 50,000 MMcf/yr savings assuming CCGT plants only. In this case, introducing OCGT, again without heat rate penalties, reduces the savings to about 30,000 MMcf/yr. Introducing heat rate penalties and using CCGT only produces savings of about 30,000 MMcf/yr as well, but the inclusion of OCGT plants reduces gas savings to almost zero.

Figure 1 – Fossil Fuel Savings

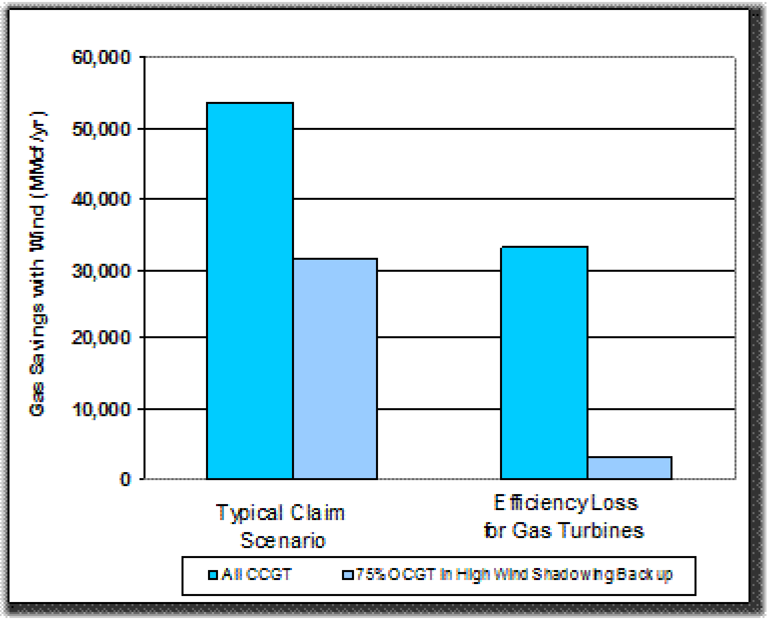
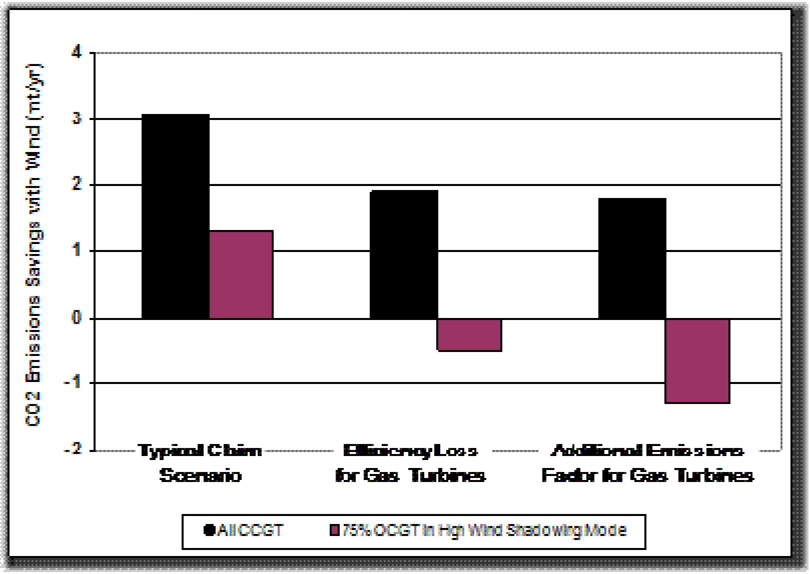


Figure 2 displays the results for CO2 emissions savings. The “Typical Claim Scenario” shows annual savings of about 3 million tons of CO2 ignoring any OCGT considerations and any effect of heat rate penalties or the related CO2 emissions increase factor. Introducing OCGT within this scenario cuts the savings by more than one-half. Using the inefficiency factors and only CCGT shows that the CO2 savings are reduced by about one-third, but introducing OCGT drives the CO2 savings into the negative category.

Figure 2 – CO2 Emissions Savings



Conclusion

Notwithstanding the nature of the calculator, robust inferences can be drawn from its results because the analysis captures a fuller range of considerations. *The general conclusion is clear: industrial wind power does not produce the claimed benefits of reductions in fossil fuel consumption and CO2 emissions when up-and-down backup generation inefficiencies are taken into account.*

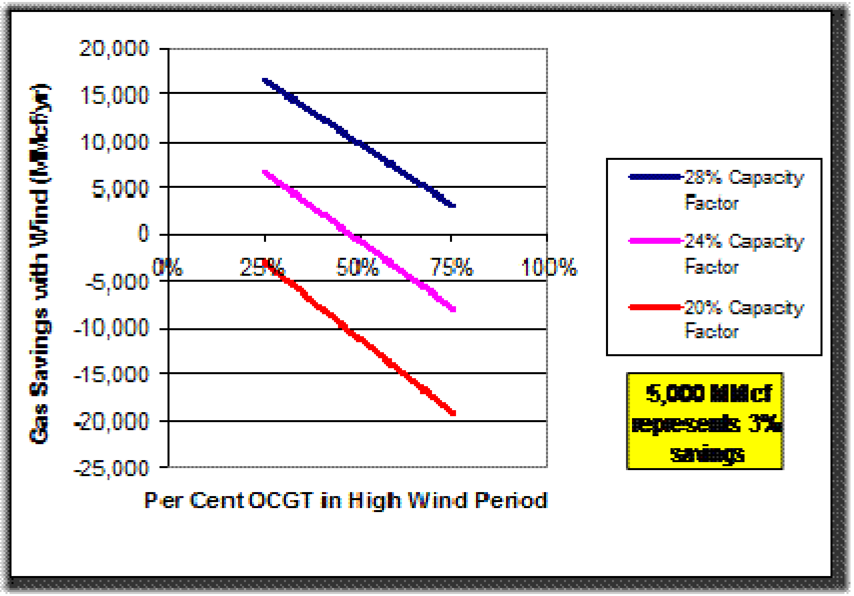
Technical Appendix: Sensitivity Analyses

To answer questions about the effect of varying some of the input parameters used, further analyses have been developed. In particular, the effects of varying the OCGT:CCGT mix in high wind production periods and the heat rate penalties and related CO2 emissions increase factors are analyzed. Also, as the calculator divides the wind year into high and low wind production periods, the effect of varying the skewing of wind production between these two periods is also presented.

Varying CCGT/OCGT Mix

The first shows the effect of varying the OCGT:CCGT mix for the wind high production period. The 25:75 ratio for OCGT:CCGT gas plants for low wind production periods is held constant for all cases shown. All other parameters are held constant. **Figure 1** shows the results for gas savings and a range of capacity factors. Negative values represent increased gas consumption.

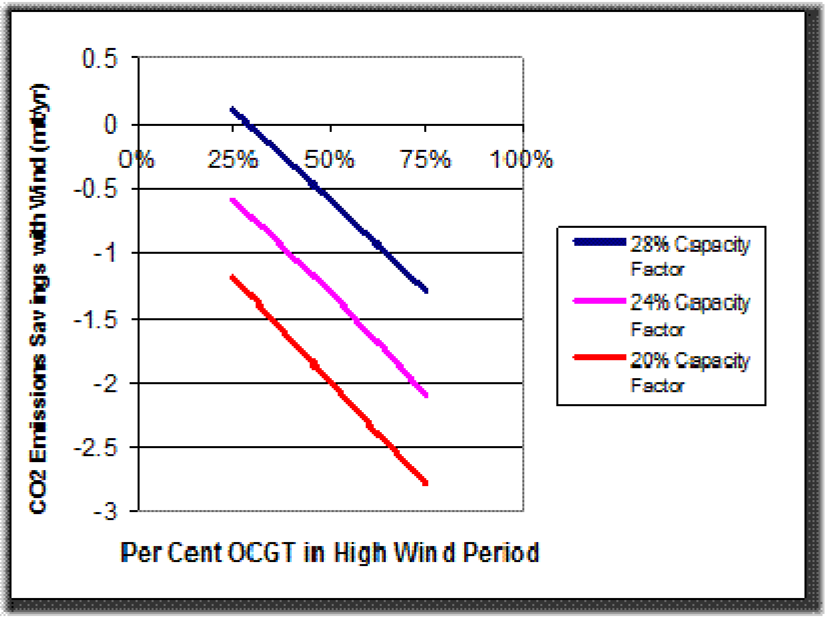
Figure 1 – Gas Savings for a Range of CCGT/OCGT Mix and Capacity Factors



Reducing the OCGT component to 25 per cent at a 28 per cent wind capacity factor still produces only about 25 per cent of the simplistic, Typical Claim scenario reductions.

Figure 2 shows the results for CO2 emissions savings. Again negative values represent increased emissions over CCGT plants operating alone. Reducing the OCGT component to 25 per cent at a 28 per cent wind capacity factor yields effectively zero CO2 emissions savings.

Figure 2 – CO2 Emissions Savings for a Range of CCGT/OCGT Mix and Capacity Factors



The lower ranges for OCGT plants in the mix are likely not feasible.

Varying the Heat Rate Penalty of the Gas Plants

Some may argue that the heat rate penalties in the examples shown above are either too high or too low. **Figure 3** and **Figure 4** show the effects for the values used, plus or minus 5 percentage points for CCGT plants. This produces a range from 10 to 20 per cent for CCGT plants and 14 to 27 per cent for OCGT, with corresponding CO2 emissions increase factors. Other parameters are held constant at the values used for the 15 per cent (CCGT) and 20 per cent (OCGT) heat rate penalties calculator runs. The “x” axis is in CCGT terms.

Figure 3 – Effect of Heat Rate Penalties on Gas Savings

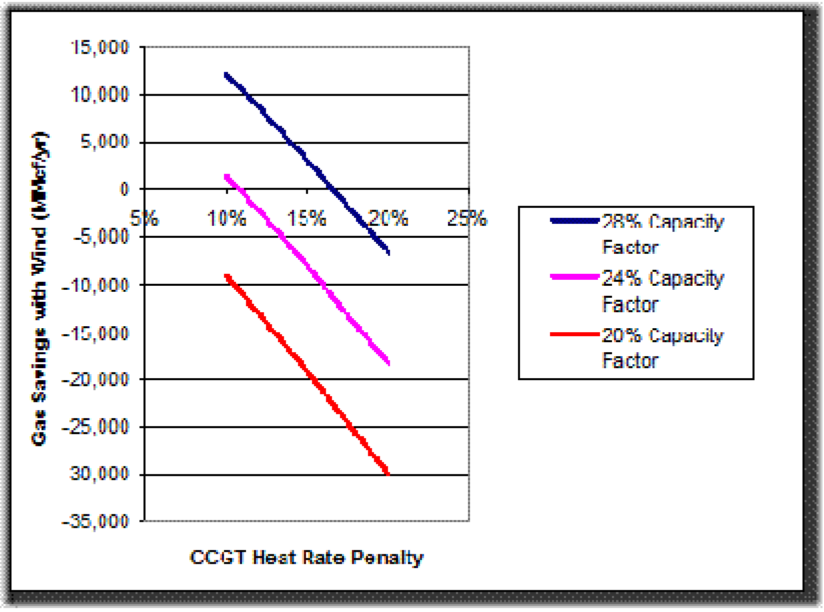
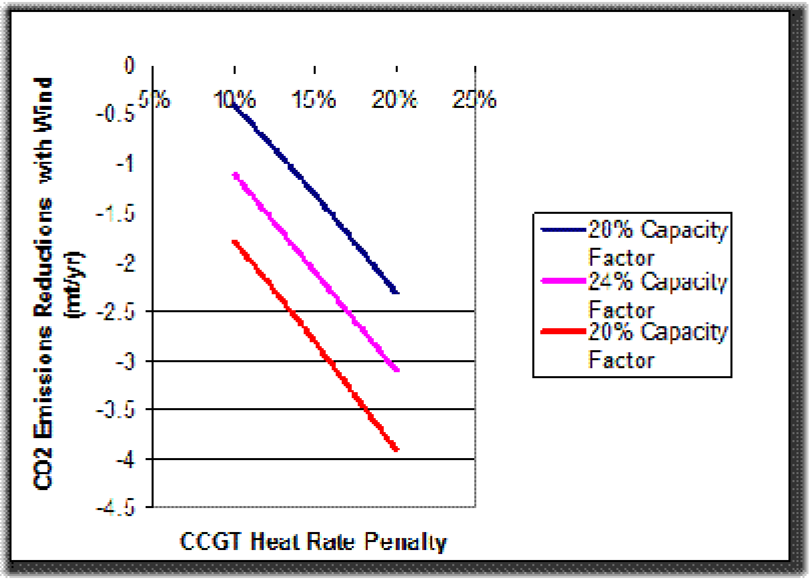


Figure 4 – Effect of Heat Rate Penalties on CO2 Emissions Savings



Values below 10 per cent for CCGT plants will increasingly support wind proponent estimates. Values above 20 per cent may be viewed by others as more applicable.

Varying the Skewing of Wind Production between Low and High Wind Periods

The calculator assumes that a year can be divided into high and low wind production periods, and allows for the variation of this by input parameter. A ratio of 50:50 was used. Further, the amount of the skewing of wind production between the two periods can be altered. For the calculator runs shown, the skewing is assumed to be the annual average plus and minus 50 percent. This sensitivity analysis shows the effect of varying the amount of the skewing from 20 to 50 per cent. **Figure 5** is the result for gas savings by varying this percentage from 20-50 per cent.

Figure 5 – Gas Savings for a Range of Skewing Wind Percentage and Capacity Factors

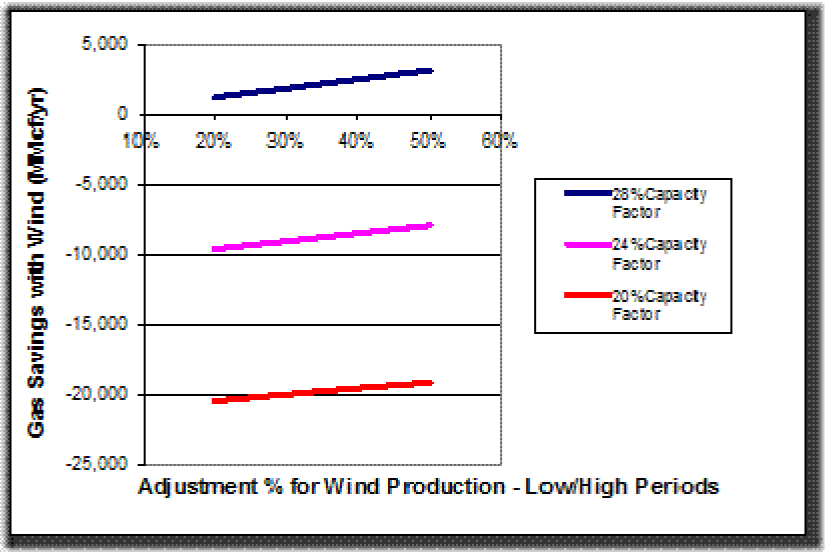
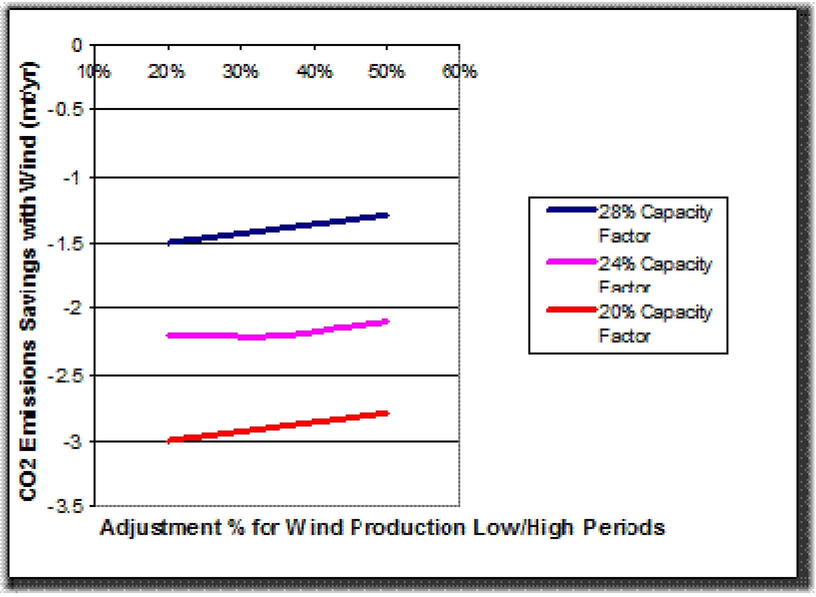


Figure 6 shows the effect on CO2 emissions savings.

Figure 6 – CO2 Emissions Savings for a Range of CCGT/OCGT Mix and Capacity Factors



In general, the effect of reducing the range of variation between the low and high wind production periods is to reduce savings. This is caused by a decrease in wind production in high wind periods, resulting in increased gas plant production, especially OCGT. So the use of 50 per cent is more beneficial to wind.

The effect of these sensitivity analyses is to support the above conclusions.

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Kent Hawkins, a retired electrical engineer living in Ontario, has spent the last eight years researching the integration of industrial-scale wind plants into electricity systems. He can be reached at kenthawkins@rogers.com.

Wind Integration: Incremental Emissions from Back-Up Generation Cycling (Part II)

by Kent Hawkins
November 16, 2009

My initial post, "Wind Integration: Incremental Emissions from Back-Up Generation Cycling: (Part I: A Framework and Calculator)," provided an overview of a fossil fuel and CO2 emissions calculator. It showed that industrial wind plants do not provide the claimed reductions in these important areas, which brings into question their value as good public policy.

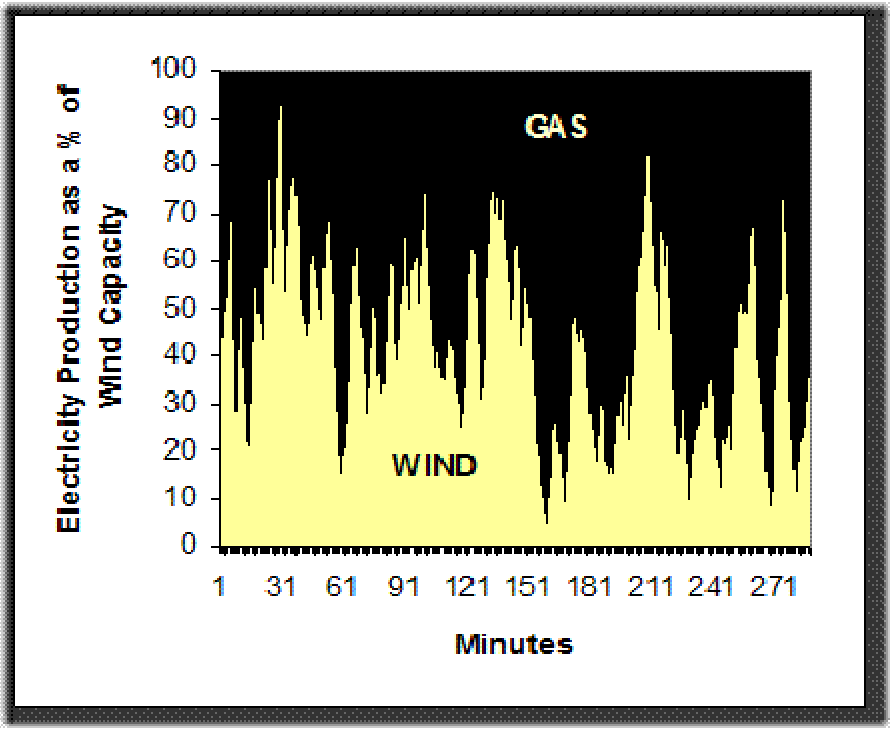
This post provides some background, a base case and the results of taking necessary additional considerations into account. The base case has two scenarios.

The first is that every MWh of wind production directly reduces the full fossil fuel consumption and CO2 emissions for every MWh of the "displaced" fossil fuel plant, which is a very simplistic view. The second takes some limited considerations into account, which can show that as much of 85 percent of the simplistic-view savings are still achieved. Calculator runs illustrate how similar results can be produced.

Background

A major consideration is the need for fast-responding gas generation plants to mirror or shadow wind's highly volatile output, especially during periods of high wind production. Figure 1 illustrates the concept. The gas production is shown in black and is necessary to render wind's output useful. As the gas production is the complement of that for wind, the vertical axis has to be read in reverse for gas. While operating in a wind-shadowing/wind-mirroring backup role, the gas turbine plants consume more gas and produce more CO2 emissions per MWh than in their normal mode of operation.

Figure 1 – Illustration of the Shadowing/Backup Concept



The calculator treats these two considerations separately. The first, fossil fuel consumption (gas) per MWh, is increased by an efficiency loss factor, or heat rate penalty. The second, CO2 emissions per MWh, is increased by another efficiency loss factor, which is greater than the heat rate penalty and non-linear. This second factor is derived from a paper by White and is not in addition to the heat rate penalty.

The calculator credits wind with the full electricity production contribution as measured over a year, regardless of its short term volatile nature. The question is: what is the effect on gas consumption and CO2 emissions for the combination of wind and gas? As indicated, it is often claimed that industrial wind plants reduce fossil fuel consumption and CO2 emissions by an amount obtained by multiplying wind's electricity production (in some measure of watt-hours) times

- A fuel consumption factor usually taken, for example, as that for a gas turbine in a normal operation mode, for the first value; and
- A CO2 emissions factor per watt-hour, usually an electricity system average or marginal value, for the second.

This will be referred to as the typical claim. It is often made by wind proponents, including government bodies wishing to promote an industrial wind power policy.

However, the literature on the subject shows a range of opinion for reductions from this typical claim, from only 10-15 per cent through to a total offset and even to the possibility of actual increases in fossil fuel and CO2 emissions. White provides an extensive review of the subject. As an example beneficial to wind, Katzenstein and Apt conclude that there should be only a small reduction from the typical claim, but their analysis requires careful evaluation. Whatever amount claimed, almost all ignore one or more of the factors described in the first post.

As a general comment, and as already mentioned, more comprehensive representation over the range of gas plant production in wind-shadowing/backup mode and wind volatility on a short time interval basis would be needed to produce more accurate fossil fuel use and CO2 production than the calculator. In the absence of such analyses, this calculator represents a good approximation of these effects.

Further, for applicability to a specific jurisdiction, demand characteristics and existing and planned generation plant portfolios would have to be taken into account.

Base Case

As indicated, there are two scenarios:

1. The first is that which is often claimed by wind proponents and policy makers and is a simplistic view.
2. The second shows the results of introducing a heat rate penalty for CCGT plants used in the wind-shadowing/wind-mirroring backup role. The CO2 emissions increase factor is ignored at this point. This indicates how some analyses, not necessarily by wind proponents, can demonstrate some fossil fuel and CO2 reductions, but less than the above simplistic view.

The wind and gas plant parameters are the same as shown in the initial post.

Figure 2 shows the gas savings in millions of cubic feet per year (MMcf/yr) for the two scenarios. The first, “Typical Claim,” assumes there is no inefficiency factor (heat rate penalty) applied and that every MWh of wind production saves the natural gas consumed by the equivalent gas plant production in normal operating mode. The second shows the reduction due to a reduced efficiency in the gas plant of 15 per cent, which causes increased gas consumption reducing the claims made for wind by 39 per cent.

Figure 2 – Base Case Fossil Fuel Savings

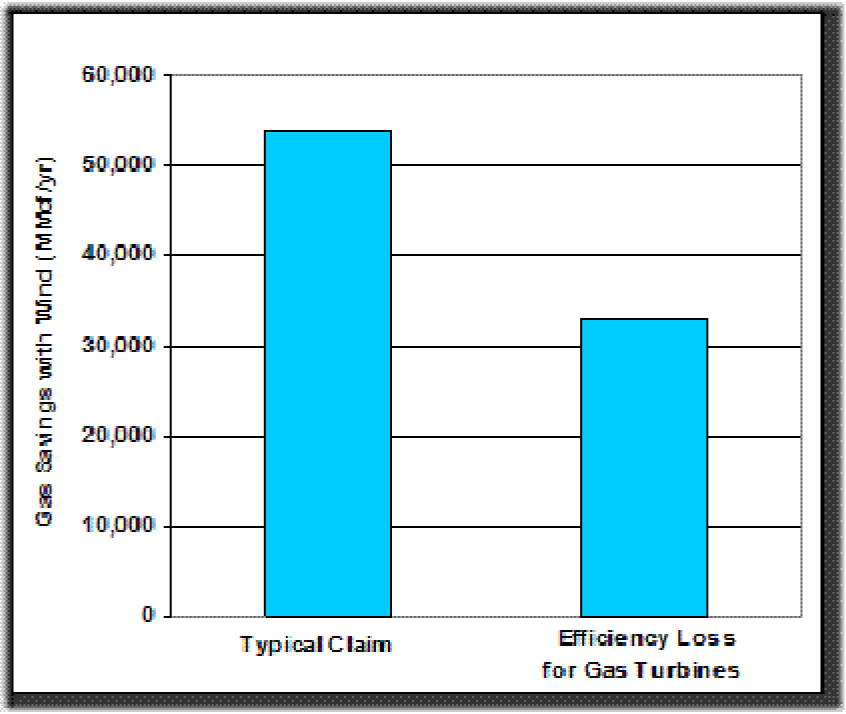
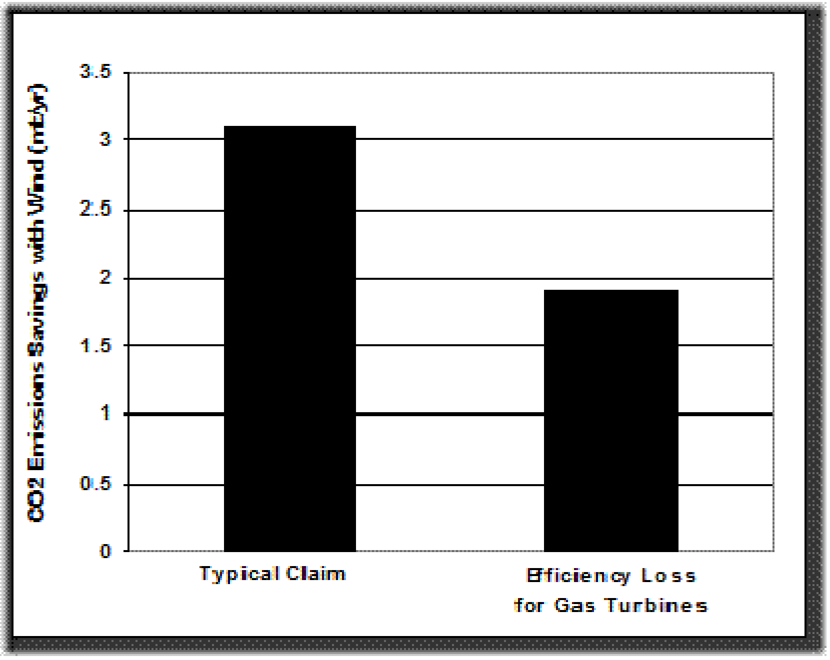


Figure 3 shows the CO2 emissions in million tons per year (mt/yr) based on the same considerations. The same percentage reduction in CO2 emissions occurs.

Figure 3 – Base Case CO2 Emissions Savings



Based on these results, which involve limited considerations, it can be seen how it is possible that some analyses show a degree of savings with the introduction of wind plants. If the gas turbine heat rate penalty is reduced to 10 per cent, the reductions become 17 per cent, that is, the calculator shows values of 83 per cent of the “Typical Claim,” or simplistic view.

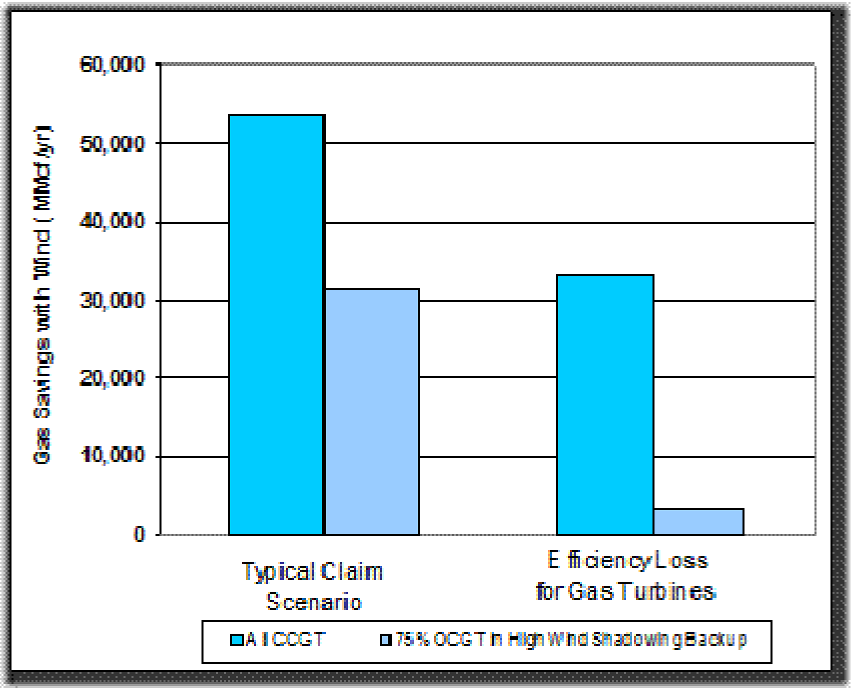
This base case will now be compared with the effects of adding the more responsive OCGT gas plants to the mix along with other factors, the results of which are very dramatic.

Inclusion of OCGT Plants and CO2 Emissions Increase Factor

The results shown are for a 75:25 mix of OCGT:CCGT for half the year (assumed high wind production) and 25:75 for the other half (assumed low wind production). This is an input parameter for the calculator that can be varied as well as the percentage of the year to which they apply.

Figure 4 shows this effect on gas consumption. The term “Typical Claim Scenario” is used to capture the change to the “Typical Claim” as a result of using OCGT plants.

Figure 4 – Effect on Fossil Fuel Savings of Introducing OCGT Gas Plants

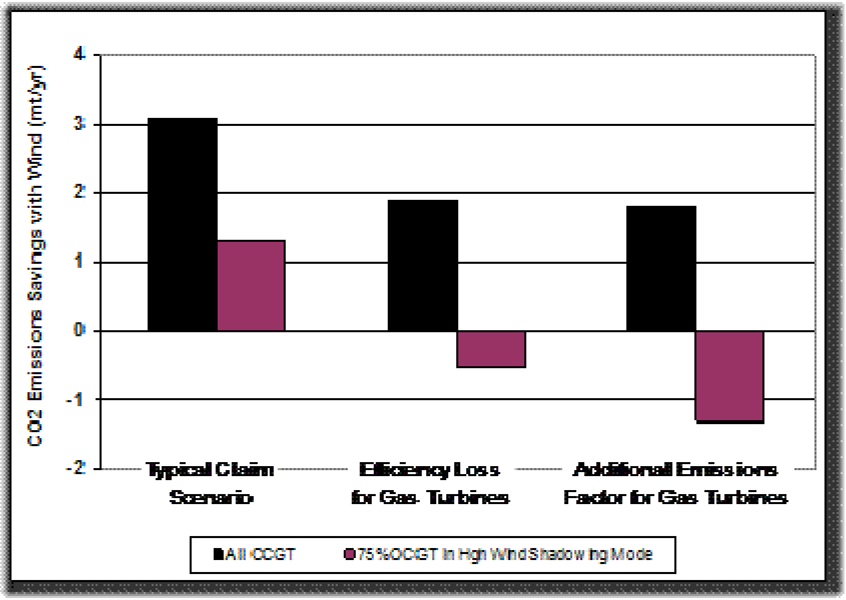


Just introducing OCGT gas plants reduces the gas savings by over 40 per cent as shown in the typical claim scenario. The effect of CCGT 15 per cent heat rate penalty plus the inclusion in the mix of OCGT gas plants, with a heat rate penalty of 20 per cent, reduces the gas savings to almost zero.

Figure 5 displays the effect on CO2 emissions. Note that with the introduction of OCGT plants:

- Even including only the heat rate penalties of 15 per cent for CCGT and 20 per cent for OCGT plants, without the additional factors for CO2 emissions, the emissions reductions become negative, that is, there are more CO2 emissions with wind present than if CCGT plants were carrying the same load alone.
- With the associated increase in emissions efficiency factors (17 per cent for CCGT and 34 per cent for OCGT), the resulting CO2 emissions savings become substantially negative.

Figure 5 – Effect of Introducing OCGT Plants on CO2 Emissions Reductions Factors



I suggest that the reason that such results are not normally seen is in part due to the unavailability of the necessary data to perform the required analysis. As already indicated, the calculator provides an interim assessment and framework until sufficiently comprehensive studies can be performed.

Effect of Reduced Wind Capacity Factor

The previous analyses assigned wind a capacity factor of 28 per cent, which may not be achievable for a number of reasons, for example: reduced availability of good wind sites as wind penetration increases and curtailment of wind production, particularly in high wind periods, by the system operator.

The technical appendix to Part I shows the effect of a range of wind capacity factors from 20 to 28 per cent. The lower capacity factors result in further and significant increases in fossil fuel use and CO2 emissions with the presence of wind plants.

Conclusions

As with any such study, one can object to some of the considerations used in developing this calculator. Nevertheless, robust conclusions can be drawn. More detailed information on the calculator is available on request.

The next step would have to be an integrated and extensive analysis of industrial wind power output for a lengthy time series, with data provided for short time intervals of minutes, a similarly extensive analysis of gas turbine plant (and other generation plant types as desired) operation in wind-shadowing/wind-mirroring backup mode, modeled against a background of a demand profile with the same type of time series, and taking into consideration the underlying generation portfolio and grid topology. The analysis would also have to include changes in the generation portfolio as a result of the introduction of wind plants, for example the increased need for OCGT gas plants.

This appears not to have been performed to date, which is surprising given the importance of the subject. In the meantime, it can reasonably be asserted that industrial wind plants do not come close to claimed benefits in terms of reductions in fossil fuel consumption and CO2 emissions. When considerations of the impact on the gas plant used in this calculator are applied, such benefits approach zero and can be reversed to add to the electricity system consumption of fossil fuel and production of CO2 emissions.

In summary, relative to CCGT plants operating alone with the same capacity as the wind plants:

- In the high range of possible annual capacity factors for wind, at 28 per cent, with the introduction of OCGT gas plants and reduced efficiency considerations for the wind shadowing/backup, the calculator shows that the presence of wind results in:
    - Almost zero gas savings; and
    - An increase in CO2 emissions of 12 per cent.

- In the low range of possible annual capacity factors for wind, at 20 per cent, the above results become:
    - An increase in gas consumption of 10 per cent; and
    - An increase in CO2 emissions of 25 per cent.

Wind Integration: Incremental Emissions from Back-Up Generation Cycling (Part III – Response to Comments)

by Kent Hawkins
December 4, 2009

Posts at Knowledge Problem acknowledge the range of results from Part I and Part II in my series; Katzenstein and Apt; and an article by Michael Milligan et al, *Wind Power Myths Debunked*, but attribute much of the differences to characteristics of the power system to which wind power is added.

However, although results will vary by jurisdiction, the differences I reported are *not* derived from this consideration but from general issues with respect to wind power integration. Milligan claims low reductions from the theoretical maximum (negligible to 7 per cent), apparently from Gross et al's literature review, but this does not survive critical assessment.

The work of Katzenstein and Apt is cited in the bibliography to Part I, even though they show that as much as 75–80 per cent of the CO2 emissions reductions presently assumed by policy makers is realized. The reason for its inclusion is that the underlying approach is used in the calculator. The difference is that the calculator takes into account the limitations that they acknowledge in their article, for example:

- The realistic introduction of different generators providing "fill-in" power than that used without wind present.
- The limitation that emission and heat rate data they used did not cover all combinations of power and ramp rate.

Even so, according to the Knowledge Problem post, they have been criticized as overstating the need for backup power supplies by Mills et al, and that geographic diversity helps to smooth out variability. In an update to the post attention is drawn to the Milligan article. This article contains often used, and questionable, arguments to support the ability of wind to offset fuel consumption and the resulting emissions despite its high degree of variability. The following addresses some examples of these.

Milligan claim – The greater the number of wind turbines the lesser the variability. Milligan demonstrates this with two samples of data from a wind plant having several interconnection points. The sample sizes are one of 200 turbines and one of 15 turbines. The comparison is graphically displayed in Milligan's figure 3, which shows that the "relative" variability decreases as the number of wind turbines sampled increases from 15 to 200. The reason for the inclusion of the term "relative" is that Milligan "normalizes" the results by dividing the output at one second intervals by the mean of each sample.

Why show the “relative” variability, which distorts the scale, when it is the absolute variability that is important? The following calculations demonstrate this:

The mean of the 200-turbine sample is about 13 times that of the 15-turbine sample (200/15).

From the graph in Milligan’s figure 3, the variability from the mean is about 20 percent for the 200-turbine sample and 40 per cent for the 15-turbine sample.

The increase in variability with the larger sample is over 6 times greater than the smaller sample ((0.20 x 13) / (0.4 x 1)).

Figure 3 should have displayed the absolute values for comparison purposes, which would have shown increased variability with the larger number of turbines. This is to be expected because wind output is stochastic in nature and the turbines in this wind plant will be strongly positively correlated. Further, it is not clear what the inclusion of the standard deviation information and the ratio of this to the mean in figure 3 add to the comparison.

Milligan’s analysis also leaves open questions about the results of using other 15-turbine samples and much more extensive timescales.

Milligan’s conclusion that, as a result of this analysis, aggregation reduces wind variability for small-scale and large-scale geographical aggregation and all timescales is therefore questionable.

The claim of the benefits of geographic diversity does not stand up to other illustrations by Oswald, Apt, and Adams. The Adams paper shows a high degree of correlation between geographically dispersed wind plants in Ontario and the Nordic region. Hugh Sharman of Incoteco (ApS) Denmark, a Danish energy consulting firm states, “We have seen how large wind carpets, composed of many small units, can act like a single, virtual, ‘out of control’ power station.”

Milligan introduces Nordic system’s ability to balance net variability and generation response, because of existing interconnections. These connections were established to bring the relatively extensive hydro generation from this region to northern European countries. They also facilitate the export northward of Danish wind power, which would otherwise overwhelm the Danish electricity system. Adams shows a strong, positive correlation of wind output in the Nordic region even at distances of 700 km, and which remains positive at 2,000 km plus. No negative correlation is shown.

The Milligan article depends substantially on the questionable argument of the benefits of geographic diversity to support many of its conclusions.

Milligan claim – There is typically sufficient responsive generation capability already built into most electricity systems, which can handle wind’s variability. No additional *reserve capacity is required.* The Milligan article cites the Gross paper, which is generally favourable to wind. Nevertheless, the following is acknowledged by Gross, and shown in context:

"Intermittent renewable energy plants can save fossil fuel, but may also increase the amount that conventional plants must vary their output, operating in response to market signals. **This change in utilization of generation is a separate issue from the need to establish additional reserves.** These effects can be quantified using time series data on intermittent outputs and demand, and the implications for the operation of conventional stations assessed." (emphasis added)

Gross acknowledges the types of analyses needed, and not yet performed, to determine the impact as recommended in my Part I and II posts. As indicated, the Gross paper is generally favourable to wind, and is included in the bibliography in recognition of the contribution it attempts to make to the subject, and because important statements are made, which might be missed by the casual reader. I have addressed some of the considerations in the Gross paper in my *Case Study on Methods of Industrial-scale Wind Power Analysis*. (See Appendix A for comments on the Gross study.) My position is that papers representing all views should be read carefully.

There is considerable evidence from the German Energy Agency (dena) and E.ON Netz that the installed capacity of wind power is approximately 90 per cent duplicated by other generation capacity, and this duplicate capacity is in excess of that needed to meet peak demand plus reserves. A presentation by Hoppe-Kilpper, Managing Director of deENet, Energie mit System (a consortium of 90 research institutions and service providers in Germany) graphically demonstrates this on slide 13.

Milligan claim – The reserves needed to balance variations in net load (the effect of the combination of demand and wind) are less than the sum of reserves needed to balance variations in the load alone or the wind alone. This is based on the fact that wind power does not correlate with the variability of load. Presumably Milligan means that the correlation is close to zero, versus the unlikely expectation of significant negative correlation. Zero correlation produces a random result, with reinforcement just as likely as opposition, not a generally offsetting one. In this case, the conclusion should be that the variations will be greater with wind present.

Milligan claim – Grid operators in some countries are gaining experience with higher penetrations of wind and with the variability of wind power. Denmark is cited as a good example of handling high penetrations, but no mention is made of the fact that it does so by exporting most of the wind production to Norway and Sweden where it is absorbed by their relatively large hydro generation facilities.

Milligan claim – The impact of forecast errors for individual wind plants is not much of a concern. The aggregate forecast error of all the wind plants is what drives the errors in committing and scheduling generation. Again Milligan relies on geographic diversity, and, as usually claimed by wind proponents, that good forecasting is beneficial. For example, sometimes average deviations from forecast over time are quoted and used as the basis for the need for limited, additional reserves. The reality is that it is the real-time performance of wind power that the electricity system has to deal with, not an average deviation for forecasts over time. Even if the forecast was 100 per cent accurate does not change the real-time impact on wind shadowing/backup capacity. So wind forecasting is not an important or relevant factor. Amongst considerable questionable treatment of the subject, Gross also has this to say:

"However fuel saving may be partially offset by a range of *efficiency* impacts:

· More frequent changes in the output of load following plant and/or greater use of flexible plant to manage predicted variations. This may decrease the efficiency of thermal plant and cause more fuel to be burnt. Frequent start up and shut down of certain types of plant can use a lot of fuel to 'warm' plant, without generating any electricity. The way such changes are provided for is also affected by the accuracy with which fluctuations can be forecast. In general terms better forecasting results in fewer losses, since the most efficient changes can be planned. **However improved forecasting does not eliminate these costs, since the need to manage predicted fluctuations will still lead to the effects described above**." (emphasis added)

The question remains: what is the amount of impact? Gross's assumption of a "partially offset" result is not substantiated without the called-for detailed studies.

Milligan claim – The UKERC determined that the "efficiency penalty" was negligible to 7% for wind penetrations of up to 20%. This also refers to deductions in CO2 emissions from the theoretical, and appears to be from the Gross et al paper listed in the bibliography. First, no jurisdiction absorbs this level of penetration domestically in energy terms. Second, the four studies mentioned appear to be those in Gross's Table 3.8 that use the Gross-defined C2 and C5 metrics. Of these, three pre-date the turn of the century, when less than 20 per cent of the wind capacity world-wide was installed and two of these are dated 1981 and 1983, when wind capacity, and experience, were minimal.

Milligan claim – Wind power costs compare favourably to nuclear and coal. No attempt is made here to look at all the pricing representations used. However, it is interesting to note two important considerations, in connection with capital cost per unit of energy produced. A very aggressive capacity factor of 40 per cent is assumed for wind and no mention is made of plant life considerations, which differ substantially. This can be as little as 10-15 years for wind turbines. The net effect of is that wind is understated by a factor of about 3 times. The other pricing claims should be looked at carefully.

In conclusion, the Milligan article is not a satisfactory treatment of the subject.

Bibliography

This contains entries in addition to the bibliographies in Parts I and II.

Adams, Tom and Cadieux François, *Wind Power in Ontario: Quantifying the Benefits of Geographic Diversity*, 2009.

Apt, Jay, The Spectrum of Power from Wind Turbines, 2007.

Center for Politske Studier, *Wind Energy – The Case of Denmark*, 2009.

Gross, R. et al, *The Costs and Impacts of Intermittency*, 2006. This paper is generally favourable to wind and is cited by Milligan.

Hoppe-Kilpper, Martin, *Systems Studies and Best Practices – Germany – Results from the dena Grid Study*. See slide 13.

Oswald, James et al (See Part I bibliography)

Sharman, Hugh, *Planning for Intermittency: the Importance of Evidence from Germany and Denmark*, (emphasis is Sharman's), UK ERC Workshop – Imperial College, 2005,

The following is an addendum to the Part I bibliography:

E.ON *Wind Report 2004*

E.ON *Wind Report 2005* (English)

Wind Integration: Incremental Emissions from Back-Up Generation Cycling (Part IV – Further Reflections)

by Kent Hawkins
December 16, 2009

Three previous posts have examined the emissions problem related to intermittent industrial windpower that is firmed up with fossil-fuel generation.

1. Part I presented a framework of the necessary considerations and an interim assessment of the effects on fossil fuel consumption and CO2 emissions until sufficiently comprehensive studies can be performed in the areas indicated. This analysis shows *approximately the same gas burn and an increase in related emissions, including CO2, compared to the no-wind case.*

2. Part II reviewed the simplistic, incomplete approach that is usually claimed by wind proponents and policy makers. Introducing necessary considerations shows the dramatic, negative impacts presented in Part I.
3. Part III critically reviewed an article by Milligan et al, introduced in a post on Knowledge Problem in response to Part I. The Milligan article claims negligible reductions from the theoretical maximum and contains questionable material.

This post deals with issues raised in comments and other feedback received to date. Further comments and debate on new issues will continue this series.

Reciprocating Engine Gas Plants as Wind Shadowing/Back-up

It has been suggested by Donald Hertzmark and Robert Peltier of MasterResource that *reciprocating engine gas plants as wind shadowing/back-up* be recognized as a partial solution to the wind emissions problem. It is also mentioned by Milligan et al.

Specifically, Midwest Energy (MWE) in Kansas has implemented a natural gas-fired plant consisting of nine 8.4 MW reciprocating gas engines to help support MWE's 325 MW total system demand and back-up power supply in the event of a transmission outage. The MWE system will also be accommodating 49 MW of industrial wind power by the end of 2009, representing 16 per cent of the peak load in capacity terms.

An additional advantage of the small multi-engine configuration is its ability to provide back-up power for the wind component. The reciprocating engines are fast-starting and represent a spinning reserve capability, which suits them for this task, especially as individual engines can be added or removed from production as needed, as opposed to the ramping up and down of a larger unit, such as a gas turbine. It is important to note that the capacity ranges for gas turbine plants start at the top end of those for the reciprocating engine plants. The question is: is this a better solution than gas turbine plants for wind shadowing/back-up?

In addressing this, some considerations are:

- What is the heat rate penalty for this configuration in a wind back-up/shadowing role? Although the heat rate for these engines is about 10 per cent greater than CCGT, it is less than that for OCGT. There are indications that the heat rate penalty is less than that of both types of gas turbine plants.
- What are the CO2 emissions per unit of electricity produced and how does this vary with frequent ramping across the full range of the complete plant? Having multiple small engines would appear to help in this respect.
- The plant has catalytic converters in the exhaust system that creates CO2 emissions through converting CO to CO2. How much does this add to CO2 emissions?
- The effect of frequent ramping and start/stop conditions on plant life, operations and maintenance compared to normal load following/peaking and infrequent back-up requirements.

- Even if the result is less emissions than the OCGT/CCGT/wind combination, what is the overall effect relative to the CCGT/No-wind case as a starting point. This should be qualified by any requirement for peaking plants not otherwise provided for in the no-wind case.
- How well can this configuration scale to larger power systems in terms of gas supply and coordination of units?

Here are some numbers that put the relative size of gas turbine and reciprocating engines in perspective. For a larger scale wind capacity of 3,200 MW, as used in the previous calculator sample runs:

- The number of engine-generator sets would involve 5-8 gas turbines and about 380 reciprocating engines.
- The number of plants would be 1-4 for gas turbines and 63 for average-sized reciprocating engine plants of 6 engines each. The total acreage required for these plants is not clear, possibly because of storage considerations, but from the information available appears to be about the same in total.

The consensus amongst those asked to review the idea was that this approach would probably not scale well to larger wind implementations in the many-thousands-of-megawatt range. One consideration is the need to deliver gas to the sites. Although there may be some application for such gas plants in small, more localized installations, the question remains: why bother with introducing wind into the mix? Further detailed studies might provide answers.

There is another issue related to this. The calculator does not take into account the consideration that multiple gas turbine engine-generator sets provide the ability to allow some gas turbines to run more efficiently than the calculator results might show. Countering this are other considerations, such as, the grid topology may not allow this type of co-operation of plants across an electricity system.

Campbell Paper Considerations

This is to further address the considerations raised by the Campbell paper and more completely answer a question raised in the comments to Part I.

Campbell addresses issues surrounding the substitution away from baseload generation to peaking and mid-merit, and intermittent sources, as the result of increasing intermittent production. During peak hours the substitution is to peaking and mid-merit, and, during off-peak, is assumed to be to intermittent sources. He finds that if peaking and intermediate technologies are more carbon intensive than non-renewable base load technologies, this substitution can more than offset the emission benefits derived from the output of the renewable technology.

In the case of off-peak periods, a closer look at the base load generation is necessary. Inasmuch as base load generation plants are incapable of shadowing wind output at higher wind penetration levels, peaking or mid-merit plants might have to be employed and base load production curtailed. Further, if base load generation is hydro and run-of-river, as at Niagara Falls, there is no reduction in CO2 emissions. If hydro is impounded, then closer examination is required into the correspondence of wind production with the need to conserve water supply in the reservoir to assess if CO2 emissions are saved as a result.

The calculator does not address the considerations raised by Campbell, which tend to be more electricity system specific. Within the context of the Campbell evaluation, the calculator looks at the interaction between wind and peaking and mid-merit gas turbine plants in connection with wind's random and highly volatile output, whether or not base load generation is displaced. The calculator shows the effect on fossil fuel and CO2 emissions as a result of this interaction, which is not "frictionless". In most cases the effects shown by Campbell would be additive to that of the calculator, and in a few cases perhaps somewhat offsetting.

In summary, Campbell does not take into account the interaction between wind and wind shadowing/back-up production, which is the subject of the calculator. The effects of the two approaches are most likely additive and, combined, may produce results even more disadvantageous to the introduction of wind plants than either alone.

Final Considerations

Even if some savings are managed to be squeezed out by the presence of wind, it is important to remember that the effect of such for an electricity system will be very small to negligible. This will be true regardless of how much wind is installed. The costs to realize these small gains, again if somehow they can be realized, are large in many terms, including the price of electricity and other forms of taxpayer support, the misdirection of industrial/economic activity into non-productive channels, the impact on local environments and economies, despoilment of natural settings, health and safety issues, distraction from better approaches to meet societal goals, and the divisiveness created within communities and even families.

Bibliography

In addition to the entries listed in Parts I–III:

Peltier, Robert, *Top Plants: Goodman Energy Center, Hays, Kansas*, *POWER*, September 2009.

Wind Integration: Incremental Emissions from Back-Up Generation Cycling (Part V: Calculator Update)

by Kent Hawkins
February 12, 2010

Why has California expressed concern over the EPA holding up approvals for natural gas-fired power plants?

Answer: because state regulators know that California's gas plants are crucial for establishing new wind and solar projects. After all, firming intermittent power sources is essential short of employing cost-prohibitive battery packs to continuously match supply to consumption.

But the analysis can go a step further. What if the gas backup actually runs more poorly in its fill-in role than if it existed in place of the wind and/or solar capacity? It *does* run less efficiently, in fact, creating incremental fuel use and air emissions that cancel out the fuel/emissions "savings" from wind.

Thus California should go a step further than just allowing new natural gas capacity. Regulators should rethink the rational of wind per se and block its new capacity–if only by removing the government subsidies that enable industrial wind power in the first place.

Background

Parts I to IV (links provided at end) introduced an analytic framework and calculator as a working hypothesis to assess the impact of industrial-scale wind on fossil fuel consumption and CO2 emissions. This post, Part V, provides an update to the calculator. The methodological framework has not changed, and the need for confirmation from actual performance data using extensive real-time local dispatch analysis at finely grained time intervals capable of accurately and sufficiently assessing how wind affects all the variables within the electricity system remains. In summary, the calculator:

(1) refines the emissions rates for the fuel plants modeled;

(2) improves the manner in which fossil fuel consumption is calculated, which increases the amounts previously reported; and

(3) adds a coal plant scenario.

This update also includes examples of the use of some of the input parameters to incorporate subtleties not considered in Part I and Part II.

A number of phrases can be used to reflect the wind shadowing/backup issue, for example “wind mirroring” and “wind balancing”. For ease of continued reference the terms “wind firming” will be used, and for the combination of wind firming plus wind the term, “firmed wind”. An illustration of this relationship was provided in Part II, Figure 1. Wind proponents claim that this relationship is “frictionless” and does not provide significant inefficiencies. *The updated calculator continues to demonstrate that the introduction of wind power into an electricity system increases the fossil fuel consumption and CO2 emissions beyond levels that would have occurred using efficient gas plants alone as the providers of electricity equivalent to the firmed wind.*

Derivation of Fossil Fuel and CO2 Emissions Increases

The same method is used as before and is represented graphically in Figure 1. It is derived from information in *Reduction in Carbon Dioxide Emissions: Estimating the Potential Contribution from Wind Power* and shows the effect on percent increases in CO2 emissions due to reductions in generation plant efficiency (heat rate penalty). To illustrate: a 20% loss in efficiency produces a 21% increase in CO2 emissions for CCGT plants; a 29% increase, 29% for OCGT plants; and a 28% increase for coal plants using bituminous coal. One change, the refinement, is to determine the percentage for all CO2 emissions increases from the top end of the efficiency for each plant type. This produces slightly lower values than previously used.

With respect to coal plants there are a number of variables that require assessment, such as identifying the kind of coal used and the type of plant deployed. To avoid becoming too complex, the behaviour of only bituminous coal plants is evaluated.

Figure 1 – Fossil Fuel and CO2 Emissions by Plant Type and Efficiency

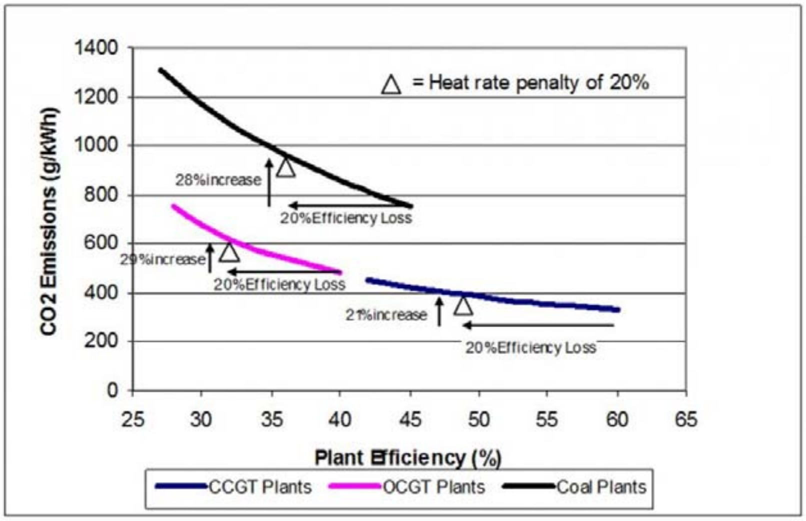
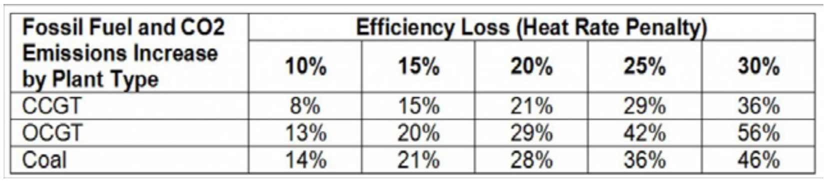


Table 1 shows the increases in CO2 emissions and fossil fuel consumption (as it is in direct proportion to the CO2 emissions) of the three plant types for a range of efficiency losses derived from Figure 1.

Table 1 – Fossil Fuel Consumption and CO2 Emissions Increase for Plant Efficiency Loss



Fossil Fuel and CO2 Emissions Increase by Plant Type	Efficiency Loss (Heat Rate Penalty)				
	10%	15%	20%	25%	30%
CCGT	8%	15%	21%	29%	36%
OCGT	13%	20%	29%	42%	56%
Coal	14%	21%	28%	36%	46%

There is inevitably some controversy about this. There are studies that show these effects are small, but close scrutiny finds them to be limited or lacking in some important way. Examples are those relying on macro analyses of a nation's energy use, with the assumption that the introduction of wind provides little or no inefficiencies at lower levels of analysis. This is the main reason why I emphasize the need for a comprehensive framework at the appropriate grid level, and have attempted to provide one. The next step remains the detailed analyses to reflect the real-time effects as described in the introduction.

To illustrate that there is a very notable impact on fossil fuel consumption and CO2 emissions from fossil fuel plants mirroring wind's frequent and extensive volatility, consider the dramatic difference in miles per gallon of gas (and resulting emissions) when driving in the start/stop, speed-up/slow-down conditions in the city versus driving at a steady rate on the highway.

In spite of this driving analogy, if you take the view that these effects are zero to negligible (and rely on studies that "establish" this), then the calculator will show results accordingly. On the other hand, there are others who will argue for higher efficiency losses than Table 1 shows, for example 40%. For the calculator runs below, mid-range values between these two opposite views were selected, rightly or wrongly assuming that this is where the action takes place.

Applying Efficiency Loss and Other Factors to Calculator Runs

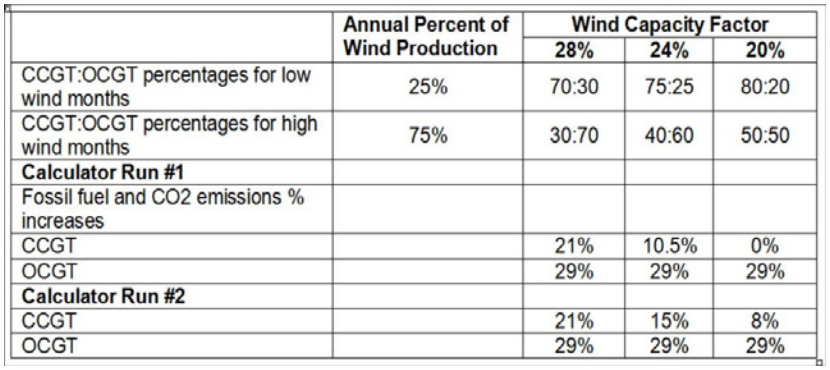
The calculator starts with a specified amount of wind capacity and calculates the electricity produced over a year (MWh/y) assuming operation at 100% capacity, ignoring scheduled and unscheduled maintenance. 100% is used as wind production can vary over its full range of capacity. This represents firmed wind electricity, which is comprised of wind (20-30%) and wind firming (70-80%) generation. The calculator compares the effect on fossil fuel and CO2 emissions of this firmed wind production to that of same generation from CCGT plants operating alone, that is, without the presence of wind in the electricity system ("no wind" case). No conclusions are made about the gas plant capacities involved.

Table 2 provides the input parameters used in the two calculator runs shown in the next section. Because wind production tends to be low for about half of the year (typically warm months) and high for the remainder (typically cool months), the calculator allows for input parameters to be different for these two periods. The proportion of the year for each and the amount of wind production in each can be varied.

Other considerations, not attempted in Parts I and II, can be looked at. For example:

- The CCGT:OCGT mixes can be altered in more detail.
- With sufficient production from fast reacting OCGT plants, CCGT plants in the wind firming role might be able to operate at higher efficiencies. In this case the calculator input for the fossil fuel and CO2 emissions increases for CCGT plants can be set at lower values, especially as the wind capacity factor decreases.

Table 2 – Input Parameters For Calculator Runs Used



	Annual Percent of Wind Production	Wind Capacity Factor		
		28%	24%	20%
CCGT:OCGT percentages for low wind months	25%	70:30	75:25	80:20
CCGT:OCGT percentages for high wind months	75%	30:70	40:60	50:50
Calculator Run #1				
Fossil fuel and CO2 emissions % increases				
CCGT		21%	10.5%	0%
OCGT		29%	29%	29%
Calculator Run #2				
CCGT		21%	15%	8%
OCGT		29%	29%	29%

As wind capacity factor is decreased it is reasonable to assume that wind volatility will also be reduced, in part due to wind curtailment during its highest and most volatile periods. This is reflected in:

- The higher percentages of CCGT in the mix
- The reduced percentage factors for fossil fuel consumption and CO2 emissions for CCGT plants.

It should be remembered that the typical wind proponent claim for fossil fuel plants in a wind firming role, based on simplistic considerations, is that there is no need for (1) efficiency loss considerations and consequently no fossil fuel and emissions increases over efficiencies experienced in “normal” operations; or (2) the introduction of faster-reacting gas plants, such as OCGT.

Gas Plant Results

Figures 2 and 3 show the results of the calculator runs for the Table 2 parameters. In all cases the fossil fuel consumption and CO2 emissions show an increase with the presence of wind (negative values in the charts).

As might be expected the increased gas consumption and CO2 emissions with the presence of wind increases as the wind capacity factor increases. This reflects the increased amount of volatility of wind production, especially during high wind production periods.

Figure 2 – Fossil Fuel Savings Compared to "No Wind" Case

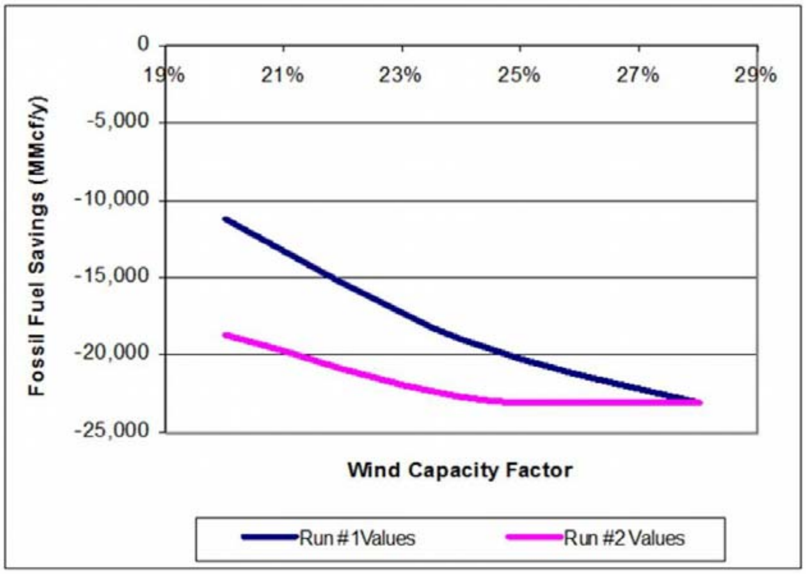
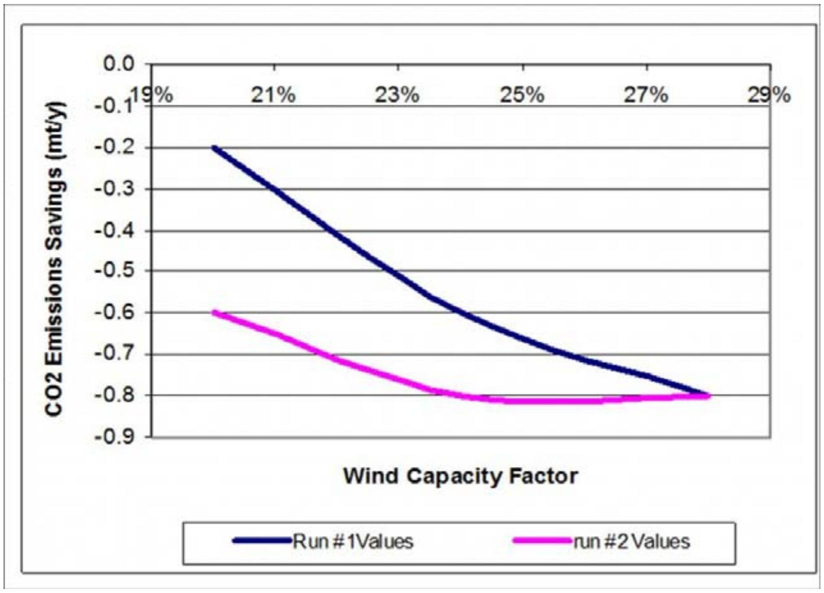


Figure 3 – CO2 Reductions Compared to "No Wind" Case



If it is assumed that the CCGT plants in the wind firming mix are somehow able to operate normally throughout the year, then the results show a fairly consistent level of savings of about -0.2 mt/y of CO2 emissions over the range of wind capacity factor shown.

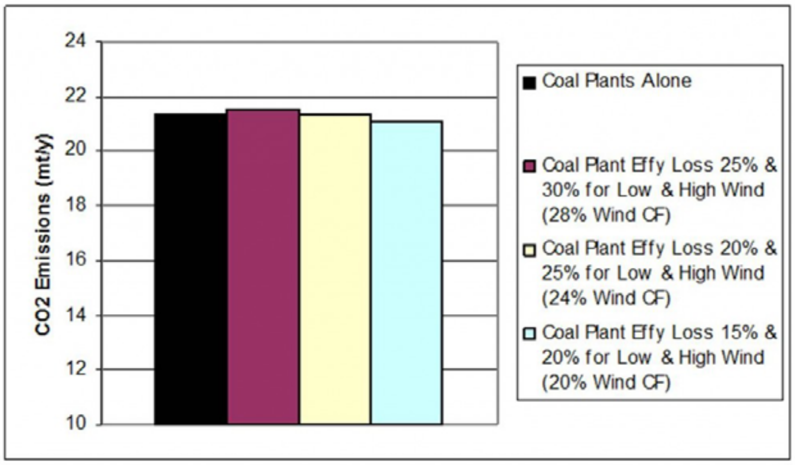
Coal Plant Results

Figure 4 shows the CO2 emissions from coal plants under several circumstances:

- The first case is a coal plant capacity operating alone providing electricity at the capacity of prospective wind plants. In these circumstances the coal plants emit 21.3 million tonnes of CO2 per year (mt/y) assuming 0.76 tonnes/MWh (t/MWh) at an efficiency of 45%.
- The following scenarios show the CO2 emissions as a result of introducing wind plants of the same capacity. So wind and coal are sharing the associated electricity generation, with wind's proportion set by the wind capacity factor. A capacity factor of 100% is used for coal because it is presumed to be a portion of the total coal plant capacity in the electricity system. Now this sub-set of coal plant(s) is operating in a wind firming role, assuming for this illustration that they are capable of doing so. A range of coal plant efficiency losses (heat rate penalties) is used as well as wind capacity factors (CF) is shown. Arguably heat rate penalties of even 40% might apply.

The calculator shows that any reductions in CO2 emissions at the point of wind plant generation are effectively offset by the reduced efficiency of the coal plants. Note the y-axis scale has already been shortened.

Figure 4 – CO2 Emissions for Coal Plants Alone versus Acting as Wind Shadowing/Backup



The following section extends this view of total CO2 emissions to include the effects of introducing gas turbine plants in the wind firming role.

Summary of a Range of Scenarios for Displacement of Coal Plant Production

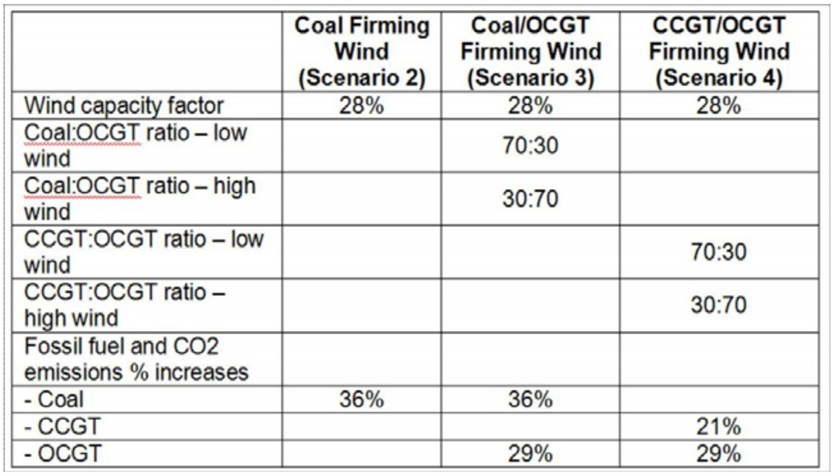
Many jurisdictions have an electricity generation profile showing a large proportion of coal, some gas, perhaps some nuclear, and often little hydro. The conventional wisdom is that wind power can be used to replace/reduce the coal production. To put this into perspective the following scenarios are used.

1. The base case shows the CO2 emissions from the coal plant production being displaced, as shown previously in Figure 4. The coal plant production is the equivalent to the proposed firmed wind plant production over a year.
2. This shows the affect of adding wind using coal acting alone as the wind firming generation, also as shown previously in Figure 4. The question is: are coal plants are able to do this over the full range of wind volatility? Wind proponents claim that, with the introduction of wind, the coal plant CO2 emissions will be reduced by the amount of wind production. The calculator shows otherwise.
3. OCGT plants are added to the mix to assist coal in the wind firming task. The coal/OCGT mix used is shown in Table 3.
4. To eliminate the coal production a combination of CCGT and OCGT gas plants is used for wind firming.
5. Finally, the result of replacing the coal production using CCGT plants alone is shown (no wind case).

In all cases the wind production is set by its capacity factor, and the wind firming production is the balance.

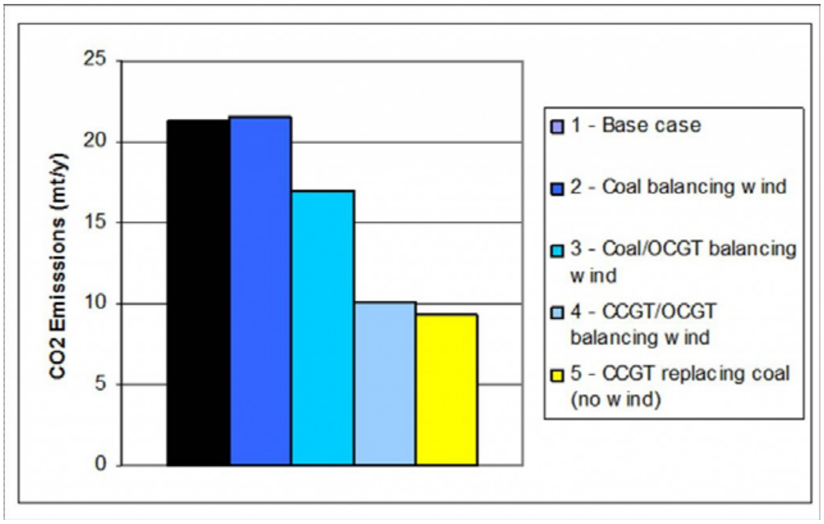
Table 3 shows the input parameters used to produce the results in Figure 5 for scenarios 2, 3 and 4. Scenarios 1 and 5 are the CO2 emissions for coal and gas plants respectively, operating normally and producing steady electricity.

Table 3 – Input Parameters for Figure 5



	Coal Firming Wind (Scenario 2)	Coal/OCGT Firming Wind (Scenario 3)	CCGT/OCGT Firming Wind (Scenario 4)
Wind capacity factor	28%	28%	28%
Coal:OCGT ratio – low wind		70:30	
Coal:OCGT ratio – high wind		30:70	
CCGT:OCGT ratio – low wind			70:30
CCGT:OCGT ratio – high wind			30:70
Fossil fuel and CO2 emissions % increases			
- Coal	36%	36%	
- CCGT			21%
- OCGT		29%	29%

Figure 5 – Comparison of Coal Replacement Scenarios



This illustrates the point that the important question with respect to the effect of the introduction of wind is not what electricity production means is being displaced, but what is acting in the wind firming role. This is shown by the result that the wind firming generation would be more effective without wind. *In effect, wind is displacing the firming production, and the firming production is displacing coal.*

There can be an exceptions to this, for example with the availability of sufficient impounded hydro supply to firm wind as discussed in Big Wind: How Many Households Served, What Emissions Reduction? (Part 2). However, most jurisdictions do not have this luxury.

Conclusions

It is not my intention here to advocate a specific generation means for any jurisdiction, but rather to illustrate the effects of wind penetration on fossil fuel consumption and CO2 emissions across a range of probable policy choices. *What emerges from this analysis is that in electricity systems that must choose among fossil fuel-fired means of integrating wind volatility, no plausible scenario seems to exist where wind can play a positive role as the means to achieve fossil fuel or greenhouse gas emissions savings.*

Appendix: Links to Previous Parts of this Series

1. Part I presented a framework of the necessary considerations and an interim assessment of the effects on fossil fuel consumption and CO2 emissions until sufficiently comprehensive studies can be performed in the areas indicated.
2. Part II reviewed the simplistic, incomplete approach that is usually claimed by wind proponents and policy makers. Introducing necessary considerations shows the dramatic, negative impacts presented in Part I.
3. Part III critically reviewed an article by Milligan et al, introduced in a post on Knowledge Problem in response to Part I. The Milligan article is an example that

claims negligible reductions from the theoretical maximum and contains questionable material.

4. Part IV reviewed considerations involving reciprocating engine gas plants for wind firming and the paper by Campbell which addressed the effects of substitution away from baseload generation to peaking and mid-merit, and intermittent sources, as the result of increasing intermittent production.

For a copy of the calculator contact the author at kenthawkins@rogers.com.