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The Overlooked Environmental Cost of a Wind Generation Portfolio to Serve the Need for Power

By Lincoln Wolverton and Raymond Bliven

The November passage of Initiative 937 adds Washington to the states with renewable portfolio standards. Wind-powered generation is a resource of choice in meeting renewable standards, and it has been highly touted for its environmental benefits. Considered in isolation, the environmental benefits of a wind resource are undoubtedly warranted. However, it is misleading to consider wind on an isolated basis—that is, outside of the context of the full power-supply portfolio that is necessary to serve load. In the context of an integrated portfolio, much of the environmental benefit disappears and may even be non-existent as compared with other resource portfolio choices.

In particular, a full assessment of the impact of wind resources on the environment necessitates a look at the *energy* consequences of adding wind-generation to an integrated portfolio in the context of meeting load.

Accounting for energy, it is likely that there is no significant environmental difference between a resource portfolio adding wind generation and one adding high-efficiency combined-cycle gas turbines. It is also likely that the wind-based portfolio results in little reduction, if any, in the need for fossil fuels and therefore little reduction in the exposure to their price swings and environmental consequences. That is, the emissions and fossil-fuel impacts of a wind-based portfolio appear little better than a non-wind-based portfolio.

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Resource choices are not isolated from each other nor are they independent of load considerations. The objective of any plan for a resource-development portfolio is to meet the "need for power," which will be defined, grossly, here, as the projected energy load less economic existing resources for all hours of the day/week/year.[1] Economic growth, household and commercial construction, and the actual and potential retirement of resources produce an increased demand for electric power. When that demand is compared to the existing economic resources, a need for new power sources results.

There is an infinite variety of resource combinations that can meet the need for power, of which wind-generation is one possibility. Few single, stand-alone resources can meet this need at a least environmental and economic cost, so combinations of resources must normally be identified as candidate portfolios to best meet the need for power. The societal task is to find the

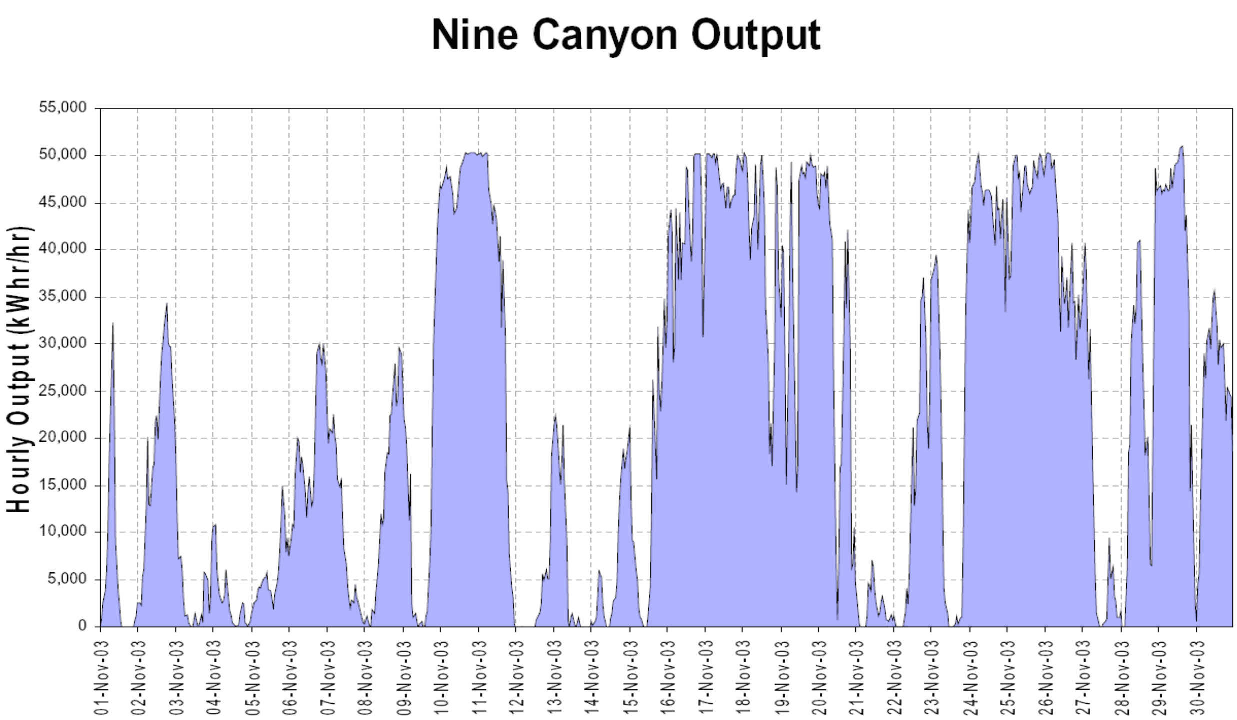
[1] A caveat: To the extent that a load or a storage alternative can be altered to accommodate the pattern of production of the wind resource—through storage of water behind dams, pumped storage, etc.—the problem is reduced.

portfolio of resources that meets society's objectives of least cost and risk at the same time as meeting environmental constraints.

Wind generation cannot meet the need for power as a stand-alone resource. Other resources are needed to fill the residual between the need for power and the output of the wind resource, or load will not be served. In short, the wind resource can be only part of a portfolio.

Any measurement of the environmental effects of a resource like wind needs to assess the impacts of the total portfolio or set of generation resources that are necessary to meet the need for power, not just the stand-alone wind resource. The economic and environmental impacts of the set must be considered and compared to other portfolio sets. For example, one set might consist of wind generation combined with simple-cycle combustion turbines to meet what the wind resource alone is unable to meet. Another set might consist primarily of combined-cycle combustion turbines. There are, of course, many other reasonable variations.

Wind generation has a highly variable output pattern; typical generation in the Pacific Northwest, for example, averages 30 percent of nameplate capacity, but the variation can go from 0 to 100% of capacity, sometimes within a single hour or day and certainly within a season or year. The following graphs the output of one Pacific Northwest project for November 2003.



Some of the within-day and next-day variability can be predicted and accommodated by most power systems, just as load variability can be accommodated. That is, the difference between the day-ahead projection of wind-resource output and its actual generation output in real time arguably makes little change to the total load/resource hourly balance and the existing means used to balance the system.[2]

Some-wind generation variability, however, cannot be accommodated without a backup resource. For example, if the need for power at 9 a.m. tomorrow is 100 MW, but the predicted output of a 100 MW capacity wind farm is expected to be 10 MW, another resource must be scheduled to meet the 90 MW residual need for power—that is, to supplement the "schedule" from the wind generator.

On an economic- and the environmental-effect basis, the set of resources becomes the benchmark for an assessment of impacts; in the example above, what needs to be measured is the impact of 10 MW of a wind resource and 90 MW of another resource on that hour.

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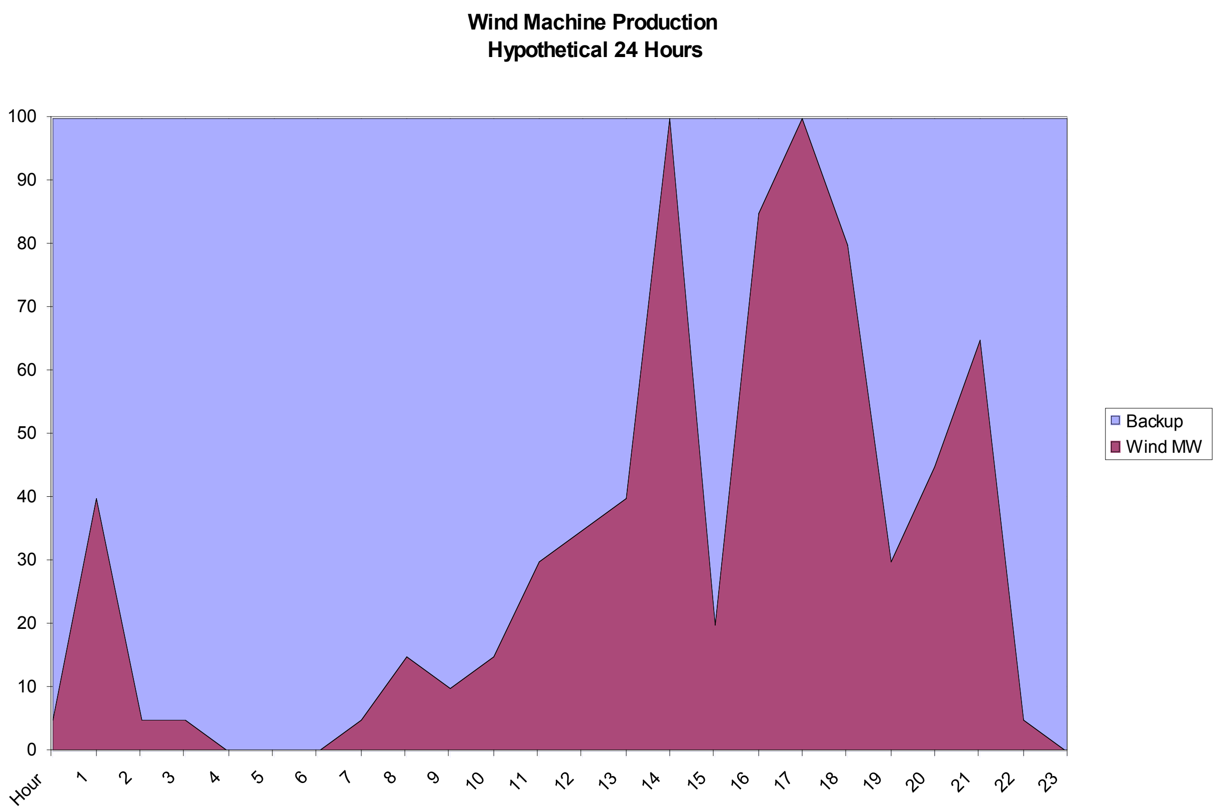
An analysis of an actual wind resource and its contribution to the need for power is a complex undertaking and beyond the scope of this paper, but the issue can be drawn with a hypothetical example and a case study.

Consider the following hypothetical need-for-power scenario: The need for power is a simple 100 MW for all hours of all the days. That is, the difference between the load to be met and existing resources is 100 MW at all times. Furthermore, assume the current system has been optimized so that there happens to be no spare capacity to meet the new need for power. Suppose that a wind-resource project has 100 MW of capacity and has a fully predictable pattern of production for each of the 24 hours of each day—as shown in the following example illustration. The resulting plant factor of the window resource is expected to be 30%, or 30 MW production on average. [Ignored in this illustration, for expository purposes, is any need for operating and forced-outage reserves.]

The illustration shows a pattern of wind-generation production that shows up heaviest in the late afternoon and evening hours, then drops off during the night. For example, wind generation in Hour 8 is 15 MW. Because of the assumption of a 100 MW need for power, the chart also shows the residual <u>energy</u> production from the other, backup resource as the difference between the level of wind production and the top of the chart. In Hour 8, the backup resource

[2] In terms of day-ahead, or hour-ahead scheduling, this paper accepts (without further analysis) studies that show that wind generation causes no more problems than do variations in any other generation sources or loads: There will be errors in forecasting both loads and generation for the next hour or day, and the power system is designed to accommodate those errors as a matter of course. See *Integrating Wind Energy With the BPA Power System: Preliminary Study, September 2002*, by Eric Hirst.

would have to be planned and scheduled to generate 85 MW in order to meet the 100 MW new load in that hour.



Turn now to the characteristics of this backup resource for this wind-based portfolio. Though the backup resource operates 70% of the day, it must be able to cycle from no production (in Hour 17, for example) to 100 MW of production (in Hour 5). The most likely resource that can accommodate that much variability (apart from stored hydroelectric energy) is a simple-cycle combustion turbine. Though the plant factor might appear to favor a combined-cycle CT, on average, the CCCT requires a steady operation to obtain its efficiency. So, in this example, the need for power is met by a wind resource and a CT operating at 70% plant factor.

The environmental impact of meeting this hypothetical <u>need for power</u> would be estimated from this combination. To get a true environmental-impact analysis of various options to meet load, this portfolio combination would be compared to an alternative—for this example, a CCCT. Supposing that the heat rate of a CT is 10,000 Btus per kWh and a CCCT is 7,000 Btus per kWh, ballpark numbers for modern resources, then a comparison of natural-gas consumption can be made:

	Wind/CT Portfolio	CCCT Portfolio
Number of hours of thermal operation per day	16.8	24
Btus per kWh	10,000	7,000
Btus needed per day per kWh	168,000	168,000
MMBtus per year	6,132,000	6,132,000

In this example, the Btus needed for the wind/CT portfolio and the CCCT portfolio turn out to be identical. To the extent that greenhouse gas (GHG) and other emissions are related to the amount of natural-gas used in a year, the environmental impacts will be identical.

The lesson to be drawn from this hypothetical example is that development of renewable energy resources, in the context of a portfolio of resources to meet the need for power, does not necessarily reduce Btu consumption versus a non-wind alternative. A change in the assumed efficiencies of the combustion turbines would, of course, produce different result, but not necessarily a better one for the wind resource.

This hypothetical example is not intended to show that a CCCT-based portfolio is similar in impact to a wind/CT-based portfolio, though in this illustration that is the result. Rather, it is intended to illustrate the importance of viewing the resource-portfolio implications of a plan to meet the need for power and to highlight the importance of the broader look at resource plans. Society's objective should be to find the least-cost method of serving the expected demand for electricity—and, by extension, the need for power. Least cost should include, of course, environmental considerations and conservation options.

Case Studies

To what extent does the hypothetical example represent the larger world? In order to test the impacts of wind and CCCT portfolios in a broader context, we used the Aurora production cost model (developed by EPIS, Inc.) to analyze the development of a wind portfolio versus a CCCT strategy in the context of the Western power system. Two studies were performed. The first test analyzed the impact of an increase of 100 MW in need for power to be met by a wind plus CT or a CCCT portfolio in a "closed" system—that is, without access to and from external markets. The second analyzed a larger need for power in the context of an "open" West-wide market. In particular, the open market allowed for diversity in wind resources throughout the West, incorporating the differing operating patterns of wind-generation sites.

The first test using the Aurora model considered a wind generator with a pattern of production from an actual project (near the Columbia River), a simple-cycle combustion turbine and a combined-cycle combustion turbine—the latter two using the typical heat rates contained in the Aurora data base. The model contains algorithms that calculate the amounts of greenhouse gas, NOx and SOx. The result is portrayed in the following table.

	Wind/CT Portfolio	CCCT Portfolio
Tons per year of SO_2 (typically)	3 (0.04 lb/MMBtu)	2 (0.0014 lb/MMBtu)
Tons per year of NO_x (typically)	235 (0.09 lb/MMBtu)	64 (0.037 lb/MMBtu)
Tons per year of GHG (typically)	349,286 (131 lb/MMBtu)	380,045 (119 lb/MMBtu)

In this Aurora simulation of an actual but isolated resource and load circumstance, the Wind/CT portfolio has higher pollutant emissions in two categories than does a CCCT portfolio.

In the second study, the wind and non-wind portfolios were allowed access to the full Western power market (including the transmission limitations incorporated into the model. In this analysis, we constructed a portfolio consisting of all current and projected wind in the West, 14,000 MW of nameplate capacity. The alternative portfolio produced the same amount of energy as the wind portfolio from CCCTs. The advantages of a larger market scope reduced the disadvantage of the wind-based portfolio, probably due to the ability to make open-market purchases when the cost of operating the combustion turbine exceeded the market price, including wheeling.

The result of this analysis is portrayed in the following table depicting the environmental impacts of the units tested and the market as a whole:

	Wind/CT Portfolio	CCCT Portfolio
Tons /year of SO_2 as % of CCCT	100%	100%
Tons/year of NO_x as % of CCCT	99%	100%
Tons/year of GHG as % of CCCT	96%	100%

What the Aurora analysis shows across the entire West is that there is virtually no difference between SO_2 and NO_x emissions as between a wind/CT portfolio and a CCCT-only option. It shows also that the wind/CT option produces 96% of the amount of greenhouse gases as does a CCCT resource constructed to meet the same load.

<u>Observations</u>

This discussion is based, of course, on a hypothetical example chosen to illustrate the point and two model test cases, so a number of observations need to be raised about broader applicability of the analysis.

1. Actual portfolios of resources and resulting environmental impacts will be specific to the wind projects considered, the characteristics of other resources necessary when wind is not available, and the need for power that their operation

helps meet. Each wind resource has different expected operating characteristics that play upon any portfolio analysis.

2. The chief problem with a stand-alone wind resource is that its operation may detrimentally affect the shape of the residual need for power that has to be served.
3. Having to plan and operate for the real-life need for power may cause greater problems for the environment with a wind portfolio than without it, because the residual may be very difficult to serve without extensive use of CTs.
4. If the wind resource can be paired with storage—a hydro reservoir, pumped storage or a load that can operate with intermittent service, then much of the load-shape problems can be removed. The opportunites to pair wind with hydro are reaching their limit.
5. The use of the wind resource is more difficult in a predominately thermal power system, because the backup likely would be the CT, as used in the example.
6. There may be diversity in large numbers of wind resources from different geographical areas to help offset the impact of any single wind resource on the residual need for power, but the ability to use that diversity depends on the current and potential future transmission system.
7. A coal/wind strategy is unlikely to meet a need-for-power objective because a coal plant normally generates electricity using boiler steam and must be operated efficiently as a base-load resource. That is, a coal plant using today's technology cannot be cycled to provide adequate backup for wind generation.
8. Planning studies, which frequently omit hourly analyses, need to consider, at a minimum, the hourly variability of wind generation on the totality of a plan.

The approach taken in this paper for examining generation—using the need for power as the basis of the analysis—considers primarily environmental impacts. There are major economic impacts as well from a wind portfolio. Just as it is misleading to look solely at the environmental effects of a stand-alone wind resource, it is misleading to consider only the economics of a wind project without considering the costs of resources needed to back up the wind generator.

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