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Comparing the Costs of Intermittent and Dispatchable Electricity Generating Technologies

By Paul L. Joskow*

The federal government and many states have adopted policies to promote the development of various renewable energy technologies for generating electricity. These policies include tax subsidies, direct subsidies, loan guarantees, purchase obligations, and long-term contracting requirements. The primary renewable generating technologies affected are wind and various solar electric generating technologies, and I will focus on those technologies here. The primary argument for these promotional and regulatory policies is to substitute no or low carbon electricity generation technologies for less costly fossil-fueled technologies absent an appropriate price on CO_2 emissions. A related argument for these policies is that experience effects will eventually make renewable technologies "competitive" with conventional generating technologies even in the absence of CO_2 emissions prices. I demonstrate here that the life-cycle cost metric typically used to compare the economics of conventional and renewable generating technologies is flawed and that an alternative market-based framework will yield more accurate economic comparisons and estimates of the actual cost of displacing CO_2 emissions.

I. Dispatchable Generating Technologies

Most conventional generating technologies (e.g., coal, gas-combined-cycle, nuclear) are "dispatchable." This means that they can be controlled by the system operator and can be turned on and off based primarily on their economic attractiveness at every point in time both to supply electricity and to supply network reliability services (e.g., frequency regulation, spinning reserves). Supplies from conventional dispatchable generators are typically increased or decreased by the system operator to meet demand by dispatching the generators to supply power with the lowest marginal generation cost or bid offer price first and then moving up the "dispatch curve," calling on generators with higher marginal costs or bid prices until the demand for electricity is satisfied in real time. To keep things simple, and ignoring market power considerations, conventional generators are typically dispatched when the wholesale market price for power exceeds their short-run marginal cost of generating electricity (e.g., Paul L. Joskow 2008).

II. Intermittent Generating Technologies

Wind, solar, and some other renewable generating technologies supply electricity "intermittently" and are not dispatchable in the traditional sense. Electricity produced by these technologies is driven by wind speed, wind direction, cloud cover, haze, and other weather characteristics. As a result, they typically cannot be controlled or economically dispatched by system operators based on economic criteria in the same way as dispatchable technologies. The output of intermittent generating units can vary widely from day to day, hour to hour or minute to minute, and location to location, depending on the technology and variations in attributes of the renewable resource that drives the turbine generating electricity. Rather than controlling how much and when an intermittent generator is dispatched, system operators must respond to what comes at them by calling on dispatchable generators to balance supply and demand continuously.

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III. Comparing Economic Values of Intermittent and Dispatchable Technologies

Proponents of renewable electricity generation often argue that one or another renewable technology is now or soon will be "competitive" with conventional dispatchable generating technologies (or that they would be competitive if we took the value of CO_2 emissions into account). The most widely used metric for comparing the "competitiveness" of different generating technologies is the estimated "levelized cost" per megawatt-hour (MWh) supplied. The "levelized cost" of supplying electricity using a particular generating technology is a measure of the real total (capital plus operating cost) *life-cycle cost* per MWh supplied. Moreover, competitive procurement programs run by utilities to meet renewable electricity purchase mandates often use auction mechanisms that effectively choose the supply offers with the lowest levelized cost per MWh regardless of when it is supplied.

The United States Energy Information Administration (USEIA 2010) recently forecast that the "levelized cost" of wind generation would be lower than the "levelized cost" of coal and nuclear by 2020 and lower than the "levelized cost" of natural gas combined cycle, nuclear and coal by 2035. The *Wall Street Journal* (September 13, 2010, page R4) recently reported results for levelized cost estimates for a wider range of electricity generating technologies. Similar "levelized cost" calculations appear elsewhere in the literature for wind, various solar technologies, and other renewable electricity technologies (e.g., Karlynn Cory and Paul Schwabe 2009; SunPower Corporation 2008). Based on the levelized cost values reported in these and other recent studies, it often appears that wind is very competitive with most base load conventional alternatives (e.g., coal, nuclear, and gas-combined-cycle) at a "typical" location, but solar has significantly higher levelized costs than wind and dispatchable base load alternatives (Liam Denning, *The Wall Street Journal*, 2010).

Unfortunately, conventional "levelized cost" is a flawed metric for comparing the economic attractiveness of technologies such as wind and solar with conventional dispatchable generating technologies such as nuclear, coal, and gas-combined-cycle. It is flawed because it effectively treats all electricity generated as a homogeneous product governed by the law of one price. Specifically, traditional levelized cost comparisons fail to take account of the fact that the value (wholesale market price) of electricity supplied varies widely over the course of a typical year. The difference between the high and the low hourly prices over the course of a typical year, including capacity payments for generating capacity available to supply power during critical peak hours, can be up to four orders of magnitude (e.g., Joskow 2008). We observe such a large variation in wholesale electricity prices because the demand for electricity varies widely over the hours of the year, electricity cannot be stored economically for most uses, and electricity demand and supply must be balanced continuously to maintain the reliability of the network. Wholesale electricity prices reach extremely high levels for a relatively small fraction of the hours in a year ($<$ 1 percent) and generating units that are not able to supply electricity to balance supply and demand at those times are (or should be) at an economic disadvantage.

It is important to take wholesale market price variations into account because the hourly output profiles, and the associated market value of electricity supplied by intermittent generating technologies and competing dispatchable generating technologies can be very different. Moreover, different intermittent generating technologies (e.g., wind versus solar) also can have very different hourly production and market value profiles, and indeed, specific intermittent generating units using the same technology (e.g., wind) may have very different production profiles depending on where they are located (e.g., on shore versus off shore).

These output and electricity price variations are not captured by traditional "levelized cost" calculations or traditional "least cost/MWh" competitive procurement mechanisms. An intermittent generating technology and a dispatchable generating technology may have the same levelized cost per MWh supplied while simultaneously having very different net economic values and profitability. Moreover, choosing between offers to supply wind or solar energy by choosing the suppliers with the lowest supply bids without regard to when the electricity will be supplied is likely to fail to lead to the selection of the highest value renewable electricity supply offers. This type of bidding framework also undervalues solar (electricity produced during the day when prices are relatively high) and overvalues wind (whose production is often more heavily weighted to off-peak periods).

IV. Numerical Examples

The examples here rely on an extremely simple characterization of an electric power system. There are two demand periods: peak and off peak. The peak period is 3,000 hours per year, and the off-peak period is 5,760 hours per year. The level of off-peak demand is 50 percent of the level of peak demand. Demand is perfectly price inelastic and there is a large existing generating capacity portfolio that is almost perfectly adequate to meet demand and associated reliability criteria. There is a competitive wholesale market with peak period prices of \$90/MWh and off-peak prices of \$40/MWh. I focus on very small incremental investments (e.g., 1 MW) so we can safely hold market prices constant. There are two technologies (one dispatchable and one intermittent) available for incremental investment. Their attributes are depicted in Table 1 along with the associated real levelized cost per MWh for each technology.[1]

The attributes for these examples have been chosen so that the levelized cost of the intermittent and the dispatchable generating technology are approximately the same. Accordingly, if we were to look only at the levelized cost calculations, the two technologies would appear to be reasonably "competitive."

The dispatchable technology will produce electricity during all hours of the year when it is available since its marginal operating cost per unit of output is lower than the wholesale market price in all hours of the year. Outages (e.g., for maintenance) do limit production to 7,884 hours in this example, and I have assumed for simplicity that the outages are all taken during off-peak hours. Column 2 of Table 2 displays the revenues, costs, and profitability of an incremental 1 MW investment in the dispatchable technology. The dispatchable technology earns enough revenue to cover all of its costs plus a small additional profit.

[1] The average base load nuclear plant operating in the United States has a 90 percent capacity factor. The average wind turbine operating in the United States has a 30 percent capacity factor. A typical solar photovoltaic facility has a 15–20 percent capacity factor.

Table 1—Hypothetical Levelized Cost Calculations

	Dispatchable	Intermittent
Construction + fixed O&M cost (\$/MW/year)	\$300,000/MW/year	\$150,000/MW/year
Operating cost (\$/MWh)	\$20/MWh	\$0/MWh
Capacity factor	90 percent	30 percent
MWh/MW/year	7,884	2,628
Levelized cost/\$/MWh	\$58.1/MWh	\$57.1/MWh

We now compare the economic attributes of the dispatchable technology with three different output profiles for the intermittent technology. Let us assume in Case 1 (column 3, Table 2) that it is windy at night (off peak) but that the wind is too calm during the day (peak) to drive the turbine. The intermittent generator then produces electricity only during off-peak periods and only for 2,628 of the 5,760 off-peak hours. The 100 percent off-peak production is an extreme assumption, but for a two period model it is not inconsistent with the performance of wind generation in California (North American Electric Reliability Corporation (NERC) 2009). A wind generating technology with these attributes does not cover its costs and exhibits a large negative profit (i.e., −\$44,880). Thus, despite having the same levelized cost as the dispatchable generating technology, the economic value of the electricity supplied by 1 MW of these two technologies is quite different. This is reflected as well in the profitability of the two generating technologies.

Column 4 in Table 2 contains the second example. The intermittent generator is now assumed to run for 50 hours during the peak period and for 2,578 hours during the off-peak period. Shifting some output to the peak period increases revenues, but not by enough to cover the intermittent generator's total costs, and investment in the intermittent technology (absent subsidies) still yields a negative profit (i.e., −\$42,380). Again the intermittent technology produces electricity with a lower value than the dispatchable technology, and the revenue that would be earned if it sold its output at market prices does not cover its costs.

The third example (column 5, Table 2) makes the extreme assumption that the intermittent technology fortuitously produces all of its electricity during the peak period (i.e., it's more like a peaking turbine that runs only

TABLE 2—ECONOMIC VALUE OF DISPATCHABLE AND INTERMITTENT GENERATING TECHNOLOGIES

(1)	Dispatchable all cases (2)	Intermittent Case 1 (3)	Intermittent Case 2 (4)	Intermittent Case 3 (5)
Peak period MWh supplied	3,000	0	50	2,628
Off-peak period MWh supplied	4,884	2,628	2,578	0
Revenues $/MW/year	$465,360	$105,120	$107,620	$236,520
Total cost $/MW/year	$457,680	$150,000	$150,000	$150,000
Profit $/MW/year	$7,680	($44,800)	($42,380)	$86,520

when demand and prices are very high than the dispatchable base load generator depicted in the example). This would be more plausible for a solar technology than for the typical wind generator since the sun shines during the day when demand and prices are relatively high, though cloud cover can both reduce the level of peak output during the day and make it more volatile (NERC 2009). Accordingly, solar technology may have a higher levelized cost than wind technology, but it may produce much more valuable electricity. Levelized cost calculations hide this important factor. In this example, if the electricity it produces were sold at market prices, the intermittent generating technology would cover its costs and earn a substantial profit (i.e., $86,520).

V. An Alternative Approach

Now that we have competitive wholesale markets for electricity, as well as electric power system models for forecasting spot prices and time-varying demand and which integrate network constraints and reliability considerations, there is no reason to rely on flawed comparative metrics like levelized costs. Instead, the economics of all generating technologies, both intermittent and dispatchable, can be evaluated based on the expected market value of the electricity that they will supply, their total life-cycle costs, and their associated expected profitability. Such an analysis would reflect the actual expected production profiles of dispatchable and intermittent technologies, the value of electricity supplied at different times, and other costs of intermittency associated with reliable network integration. This is exactly the way investors in merchant generating plants evaluate whether or not to invest.

This framework can be used as well to design better competitive renewable electricity procurement systems and can be employed to shed more light on other issues that have been associated with the growing reliance on intermittent generation, such as storage options, and the effects of intermittent generation on the costs of maintaining grid reliability. Finally, this approach will increase transparency about the costs of alternative generating technologies, the costs of subsidies provided to certain technologies, and the cost of achieving the environmental benefits resulting from promoting renewable technologies that would not otherwise be economical choices with subsidies, credits, and mandates.

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