Variability Cost of Solar

Introduction

Solar promises to be a big part of the solution for reducing carbon emissions. The idea of harvesting free energy from the eternal sun while emitting zero carbon emissions is too good to ignore. However, this “free” energy comes at a price. Direct costs associated with putting such a system in place are most commonly recognized in the form of hardware costs, installation costs, and permit costs. These factors have been the basis for the majority of project decisions. At a micro-level, containing a cost-benefit analysis to only these factors may suffice. At a macro-level system perspective, containing analysis to only these factors will provide an incomplete picture and underestimate solar’s costs. The inclusion of additional factors of variability is vital to account for the complete costs of solar. The issue of solar variability boils down to its fluctuating availability as well as our inability to store/control it as we do fossil fuels. Implementing those characteristics into the management and distribution of electricity creates additional issues for all sources of electricity. These system costs incurred need to be accounted for in order to ensure the optimal mix of energy sources.

Standard Method:

Common measures of electricity costs don’t account for cost of variability. Levelized Cost of Energy (LCOE) is the go-to measurement for how much a source of electricity costs. It standardizes the lifetime costs per a unit of energy dividing total lifetime cost by total lifetime energy production. Included are the components of investment, depreciation tax shield, annual cost, salvage value, and energy production as best explained according to Equation 1 – LCOE.

$$\text{LCOE} = \frac{\text{Total Life Cycle Cost}}{\text{Total Lifetime Energy Production}} = \frac{I - D + C - S}{E}$$

Equation 1 – LCOE (Vasudev 2011)

Where:

I represents the initial investment

D represents a depreciation tax shield

C represents annual cost

S is the salvage value of any physical assets at the end of life-cycle

E is the total energy production

This provides a good standardized comparison of energy sources as long as the analysis stays within these considerations. The problem arises when you take into consideration the different output profiles of energy sources. The shortcoming of LCOE is that, "it effectively treats all electricity generated as a homogeneous product governed by the law of one price" (Joskow 2011). Comparing the economic value of energy sources is more complicated than comparing a boiled down economic metric. The true costs can best be considered when breaking them down into different areas.

Section 2. Variability Costs

These variability costs are complicated and affect different players at different levels. The first step is identifying the costs of variability. Only then, can we start to calculate them and the effect they will have. Variability costs are enumerated as:

1) Integration: direct energy replacement and ancillary services.
2) Wear and tear: additional maintenance to compensating generators from increased cycling.
3) Capacity capital: existence of reserve capacity infrastructure.
4) Utilization: investments recouped from fewer energy hours
5) Depressed prices: Depressed market prices with deeper solar penetration creating a cost of lower future revenue.

The qualitative and quantitative components of each cost needs to be understood in order to apply them effectively and appropriately to decision analysis. While many of these may overlap, the attempt here is to identify all the costs and not necessarily be mutually exclusive in doing so. I will merely describe what the cost is and introduce one measure that has been come up for it.

2a. Integration Costs

Integration costs refer to the direct costs of compensation for the variability of solar resources. These include costs from outright energy production and costs of ancillary services. The difference between the two can in one way be thought of as merely a difference in time scales. By looking at the distribution of fluctuations at different frequencies using power spectral analysis, we can measure what we are trying to put a dollar value on. Lueken's power spectral analysis produces an important finding that power fluctuations at periods of 10 minutes are a thousand times less frequent than at periods of 12 hours (Lueken, Cohen and Apt 2012).This means that slow-ramping compensation generation is more important than fast-ramping compensation generation. From this, Lueken then goes on to measure the two costs of compensatory energy and ancillary costs. Compensatory energy costs are calculated as energy needed during that hour due to a difference in actual energy produced versus predicted energy production multiplied by the price of energy at that hour. Ancillary costs for an hour can be derived from the price of up or down regulation multiplied by the needed regulation due to differences between predicted energy production and actual energy produced at each subhourly segment. These two components combine to create an annual average variability cost as simplified in equation 2:

$$\text{Annual Average Variability Cost} = \sum_{h=1}^{8760} \text{Compensatory Energy Costs}_h \sum_{k=1}^{\text{periods in hour}} \text{Ancillary Service Costs}_{h,k}$$

Equation 2 – Annual Average Variability Cost (Lueken, Cohen and Apt 2012)

Lueken calculates the costs to vary from $11 per MWh for a solar photovoltaic site to $5.20 per MWh for a solar thermal site. This is due to the ability of thermal solar to store energy for a limited amount of time. These hourly and subhourly costs take into account the unpredictability due to the deviation from the predicted energy output. It fails to take into account other effects of variability.

<u>Section 2b. Wear and Tear Costs</u>

Wear and Tear costs are increased for dispatchable generation that is ramping up and down more frequently. So, not only is there a direct fuel cost to this increased fluctuation as discussed above, but there is additional stress on the compensating machinery. Wear and tear increases repairs and decreases lifespans of machinery. The National Renewable Energy Laboratory (NREL) attempts to quantify the maintenance costs of ramping up/down and cycling on/off dispatchable generation. Their model considers bottom-up component costs, plant monitoring data, engineering assessments, and plant personnel surveys. Top-down data comes in the form of annual maintenance information, outages, and damage accumulation models. These two perspectives are combined with data on hot, warm, cold starts, load follow, trip events, and shutdowns. Their model calculates the range of impact to be from $.47 - $1.28 per MWh (Brown, et al. 2015). The cost differs based on the type of fossil fuel generation being cycled. Figure 1 – Lower Bound Cycling Maintenance Costs breaks down the maintenance cost to differing fossil fuel generators in different source mix scenarios.

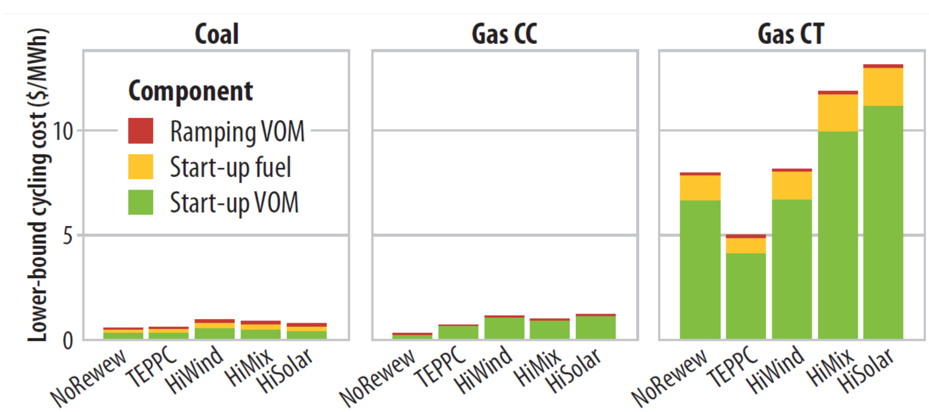

Figure 1 – Lower Bound Cycling Maintenance Cost (The Western Wind and Solar Integration Study: The Effects of Wind and Solar - Induced Cycling on Wear-and-Tear Costs and Emissions 2013). Coal, Gas Combined Cycle, Gas CT

These wear and tear costs are calculated beyond the base level maintenance costs. It is important to consider the effect that varying solar sources will have on the wear and tear of existing machinery.

Section 2c – Capital Capacity Costs

Capacity capital costs refer to the infrastructure that needs to be kept on reserve for when it needs to compensate for solar. Normally, new capacity projects would allow for avoidance of other capacity projects. However, with solar, dispatchable capacity still needs to be on hand to compensate for when solar isn't producing. This is principally a concern during peak hours when total producing capacity is most critical. We can define this cost by focusing on capacity during these peak hours. The capacity value (CV) metric is defined by the NREL as, "the contribution of a power plant to reliably meet demand" (Solar Energy and Capacity Value 2013). It is the energy able to be produced during periods of highest risk of not meeting demand (peak hours). Capacity values for different sources are given in Table 1 – Capacity Values.

Source	Capacity Value
Geothermal	99%
Natural Gas	95%
Hydro	95%
Biopower	91%
PV	50%
Wind	10%

Table 1 – Capacity Values (Brown, et al. 2015)

We can come up with a cost price by comparing the capacity value for solar to the capacity value of what might have been built then multiply by the capital cost of the compensatory generation that is making up that shortfall. Differencing solar and natural gas and using a capital cost of $50 for natural gas yields a cost of $22.5 per MWh of additional capital cost ((.95-.50)*$50/MWh = $22.5/MWh)). This is the capital cost of the generation needed to meet capacity restraints.

Section 2d – Utilization Costs

Utilization costs come about as more infrastructure is built without an increase in total energy hours. Therefore, the utilization rate of that infrastructure decreases and along with it, the number of hours that generate revenue. It is an extension of capital capacity costs, but moreover refers to the decreased energy-hours over which those capital costs are spread. Ueckerdt refers to this as the full-load hour reduction component. It is calculated from what's left after taking out overproduction and backup capacity requirements from the defined profile cost (Ueckerdt, et al. 2013, 31-32). The cost of full load hour reduction varies based on the penetration percentage. At 20% solar penetration the cost is calculated at about 20€ per MWh (Ueckerdt, et al. 2013, 19). Jaskow further explains implications of what this could mean when he talks about the "missing money" problem. More specifically, the "missing money" problem refers to when prices are too low to compensate for investment costs and adversely affect investment decisions for these capabilities (Jaskow 2008). The implications mean that higher costs are not only a result of market supply/demand, but necessary to cover investment. This has major and complicated implications for policy and government when attracting financing.

Section 2e – Depressed Prices

Depressed prices during the time solar is producing will come about with increased penetration of solar. Currently, the time of day when the most solar is produced aligns with peak periods and high prices. However, as penetration increases, an oversupply during this time will depress prices. This is already being seen in Germany and other countries with high variable renewable generation penetration. Germany can get up to 62% of its electricity generation from solar and wind sources during certain parts of certain days (Morris 2014). This can create negative electricity prices where producers are trying to get rid of electricity. Not only are producers not being compensated for their production during these times, but they could be losing money. It is always economical to produce solar and take any price above $0 because it has zero marginal cost. A deeper penetration of solar will exert more influence on the price of electricity as a whole. As this happens, solar energy will create depressed prices for itself when it floods the market. This will decrease its payback and the payback of all sources. Hirth uses data from Germany to calculate this effect. The value factor is defined as the ratio of the weighted average price of revenue from a specific generation to the average base price.

$$Value\ factor = \frac{Price\ of\ Solar_{weighted\ avg}}{Price\ of\ Base_{weighted\ avg}}$$

Equation 3 – Value Factor (Hirth 2013)

This value factor is shown to drop with increasing levels of solar penetration. In Germany, solar goes from 1.33 at .4% penetration in 2006 to 1.05 at 4.5% penetration in 2012. The decreasing relative price of solar to a base price can be predicted based on penetration level using a regression model. Solar has a .1 decrease in value factor for every percentage point increase in penetration level as shown in Figure 2 – Historical Wind and Solar value factors in Germany.

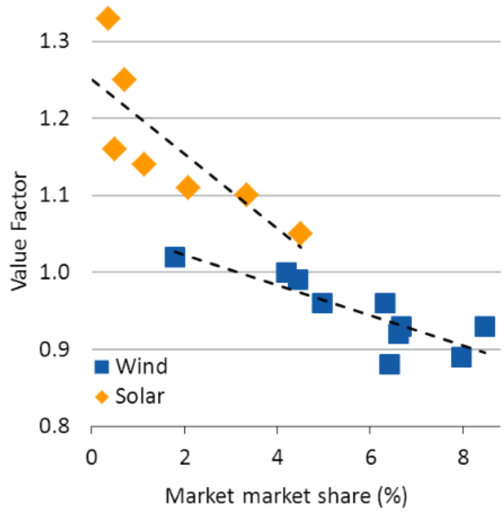

Figure 2 – Historical Wind and Solar value factors in Germany (Hirth 2013)

This makes it possible to definitively factor in the reduction in price for every added unit of solar. Future penetration of solar needs to be taken into account in this manner when making assumptions of future energy prices in models. Deeper penetration of solar will create decreasing payback to solar.

Alternative Method

One proposed method is to evaluate the LCOE of a proposed project against the Levelized Avoided Costs of Energy (LACE). The LACE contains the avoided costs to the current system by implementing the new technology. It is comprised of avoided generation and capacity costs. Avoided generation cost is calculated from the existing generation mix and the projected fuel and operating costs with that avoided generation. Avoided capacity cost is the additional capacity value that won't need to be built. It is calculated from the capacity value metrics at peak hours multiplied by the weighted average capital costs of the regional generation mix (Brown, et al. 2015, 95-97).

$$LACE = Avoided\ Generation\ Cost + Avoided\ Capacity\ Cost$$

Equation 4 - LACE

This encapsulates the costs to the current system due to defined variability costs. The difference of these two gives the Net Economic Value generated to the system by the new technology. This is outlined in the equation below.

$$Net\ Economic\ Value\ (NEV) = LACE - LCOE$$

Equation 5 – Net Economic Value

A higher NEV would mean a more attractive project. A positive NEV would mean more costs were avoided in the system than would be newly created from the project. This is one way that the EIA proposes to better understand the impact of variable renewable energy proposals.

Conclusion

The variability of solar energy sources creates completely new issues for the management of the grid. Integration with replacement energy and ancillary services, wear and tear from increased cycling, capital of increased capacity, decreased utilization, and depressed market prices are all sources of costs from the variability of solar. Defining the costs of this variability ensures that proper planning, policy, and financing decisions are made. The outcome of these decisions are a more optimal energy mix to meet the goals of low emissions energy distribution at a fair price.

Defining the costs of variability is useful when defining value to applications that can mitigate this variability. Battery storage is one energy storage device that would become more economically viable as its value is better defined. Typically, battery storage is measured in terms of the cost per unit of energy stored. While more nuanced characteristics such as power rates, capacity drop over lifetime, and maintenance costs would improve the analysis making for a more complete picture; an even better measure of a the value of a battery would be to look at the value it imparts on the system. Its value to the system is a dollar amount of the variability it can mitigate. The battery storage would then be able to be directly compared to other options of energy storage or added capacity. By drawing a more complete picture of the costs of variability in solar, the case for energy storage devices can be bolstered.

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