PV ENERGY: COST vs. PRICE IN THE MARKETPLACE

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ABSTRACT

The premise of this paper is that the fundamental economic value proposition for photovoltaic technology lies in the relationship between what we will call the *cost* and the *price* of PV generated electrical energy. When compared to other sources of electrical energy in the marketplace the value of PV energy is clouded by the fact that to date, with some notable exceptions, people and institutions wishing to buy photovoltaic generated energy (kWh) purchase photovoltaic generating systems (kW); essentially electrical generating capacity. To quantify the value of the procurement of a PV system it is necessary to relate the *cost* to produce that energy to the *price* which that energy will command in the wider energy markets. Because the energy produced by the PV system will be delivered over its (nominal) thirty year life, and because the price which that energy will bring will be determined by future energy markets we liken the PV system purchase to that of a purchase of a stock in a publicly traded company. Inherent in the present value of the difference between the PV energy's cost and price, which defines the purchaser's internal rate of return (IRR), is risk and opportunity based in the unknown future price of electricity (and uncertainty regarding secondary market characteristics) over the productive life of the PV system. This paper will describe the mathematical relationship between these two key parameters, cost and price, in a financial model which defines PV system investor's IRR.

1. INTRODUCTION

1.1 Problem Statement

This analysis treats the investment in a photovoltaic system as a cash flow problem in which we find the internal rate of return or IRR of the investment. We solve for the IRR by equating the initial cost of the installed system with the net present value of expected future monetary savings from energy produced by the system. For purposes of visualization we differentiate the *cost* to produce the energy from the future *price* it will command in the marketplace. We solve for the interest rate that makes the difference between the present value of future energy and the present cost of the PV system equal to zero. Treated purely as a financial analysis it will be clear that the parameters being evaluated as part of either the present cost or the future price of the PV generated energy may be "swapped" to the opposite side of the equation by using a sign change. For example, in our analysis we add the cost of maintenance service to the equation for the total cost of PV energy, however we could subtract it in the price equation for PV generated electrical energy and obtain the same result.

1.2 Definitions

PV system cost ($) [$PV_{sys}$]: The installed cost of a photovoltaic system.

First Cost Subsidies ($) [$PV_{fcs}$]: Financial incentives issuing from a governmental agency in the form of lump sum grants, tax credits or deductions, applied in year zero.

PV energy cost ($) [$E_{PVc}$]: The installed cost of the PV system minus the value of any First Cost Subsidies, plus the net present value of the maintenance and repairs over the life of the system. In this context, this cost is the total cost of all of the energy that is (will be) produced by a particular PV system and not the unit cost of energy.

Secondary Market Characteristics ($/kWh) [**SMC**]: In the context of this paper the primary market is the market for the electrical energy produced by the system. The secondary market is the aggregate of all public policy derived production based incentives (PBI). These include, but are not limited to, things such as renewable energy certificates, carbon credits, solar renewable energy credits, feed in tariffs and the like, intended by legislative mandate to capture and trade non-energy attributes of PV generated energy. Note that, though SMC has been cast primarily as incentives, the possibility does exist that a dis-incentive, such as a per kilowatt hour tax, could be applied to PV energy production. This case is not considered in the simulations in this paper.

PV energy price ($) [$E_{PVp}$]: The net present value of the time integrated *market* price --avoided cost (behind the meter) or sale price (busbar price)-- including secondary market characteristics, of the total energy generated over the useful life of a PV system. In this context, this price is the total price of all of the energy that is (will be) produced by a particular PV system and not the unit price of energy.

1.3 Economic Analysis Framework

A number of simplifying assumptions are made in this analysis. This analysis is for photovoltaic investment in the US market. The specific example we will employ to illustrate the detail of this analysis is set in Northern California. This model assumes the system to be a commercial installation, behind the meter, sized to be less than facility load, with annual production always be less than annual consumption. As such the model will be a case avoided energy cost at the current commercial market price of electricity. For the purpose of this model the calculations of non-energy charges associated with electricity such as delivery (transmission and distribution), time of use, and demand charges will be bundled into a simplified per kilowatt-hour rate. Market price of electricity, for future price predictions, will be modeled as a base rate of \$0.15/kWh, with a fixed annual rate of increase [1]. For computational simplification payment amounts will be calculated as their annual sum, without consideration of monthly interest, occurring at the end of the year. PV system maintenance cost will be included in the present cost of PV energy as a series of annual costs with a 2.5% annual increase on a fixed base.

All forms of grants and subsidies associated with the initial cost of the system, as well as an allocation for the Federal 30% Investment Tax Credit (ITC) are included under the heading of *First Cost Subsidies (PVfcs)*.

The term of financial calculations for the system will be 30 years based upon an assumed useful life of the system of that length of time [2]. Calculations for the mid-life major repairs of inverters will be based upon a term of 15 years at a cost of approximately 1/3 initial inverter cost.

For computational simplicity the market price of electricity is assumed to increase at a linear rate on top of the base rate of the first year of operation of the PV system.

1.4 Interest Factor Formulas

The following notation is used in calculating the time value of money for present (*P*), annual (*A*), future (*F*), and gradient (*G*) cash flow patterns [3]:

To find the present (*P*) value of an annual pattern (*A*):

$$(P/A)_n^i \qquad P = A \times \left(\frac{(1+i)^n - 1}{i(1+i)^n} \right)$$

To find the present (*P*) value of a future value (*F*):

$$(P/F)_n^i \qquad P = F \times \frac{1}{(1+i)^n}$$

To find the present (*P*) value of gradient pattern (*F*):

$$(P/G)_n^i \qquad P = G \times \frac{1}{i} \left(\frac{(1+i)^n - 1}{i(1+i)^n} - \frac{n}{(1+i)^n} \right)$$

Where *n* is the term (years) and *i* is the interest rate (%).

2. PV ENERGY COST/PRICE RATIO

2.1 PV Energy Cost

For this analysis the cost of PV energy for any PV system can be calculated by adding the net present value of all maintenance and major repairs for a PV system to the installed cost of the system. This calculation yields the cost of all of the energy produced by the system expressed in dollars.

An approximation of the cost of the energy produced by the system can be expressed as follows:

$$E_{PVc} = PV_{sys} - PV_{fcs} + S_1 (P/A)_n^i + S_2 (P/G)_n^i + R(P/F)_{n/2}^i$$

Where:

E_{PVc} is the total cost of the energy that will be produced by the PV system over its useful life, brought to the present, expressed in dollars;
PV_{sys} is the installed cost of the system, expressed in dollars;
PV_{fcs} is the total value of all grants and first cost subsidies, expressed in dollars;
S_1 is maintenance service cost in dollars in the first year, expressed in dollars;
S_2 is the annual increase in maintenance service cost, expressed in dollars;
R is the cost major repairs to inverters at year 15, expressed in dollars;
n is the number years of useful life of the PV system (30);
n/2 is the number of years before major repairs (15); and
i is the interest rate (%).

2.2 PV Energy Price

The price of the electrical energy generated by a PV system over its useful life can be calculated by summing the net present value of three factors.

$$E_{PVp} =$$
$$E_{MB}\left(P/A\right)_n^i + E_{M\Delta}\left(P/G\right)_n^i + SMC\left(P/A\right)_n^i$$

Where:

$\boldsymbol{E_{PVp}}$ is the total price of electrical energy produced by the PV system over it useful life, brought to the present, expressed in dollars;
$\boldsymbol{E_{MB}}$ is the annual PV system energy production (kWh) times the market price of electricity ($/kWh) in first or "base" year of system operation, expressed in dollars;
$\boldsymbol{E_{M\Delta}}$ is the annual PV system energy production (kWh) times the average annual change in market price ($/kWh) of electricity, expressed in dollars;
n is the number years of useful life of the PV system (30); and
SMC is the annual PV system energy production (kWh) times the aggregate monetized unit value of secondary market characteristics ($/kWh), expressed in dollars. In this example we assume all SMC to be positive, i.e. financial incentives.

2.3 Calculation of IRR

Internal rate of return is defined in this analysis as the interest rate at which the cost of the electrical energy generated by the photovoltaic system --including future maintenance cost brought back to the present— is equal to the net present value of the price of the electrical energy which would have to be purchase at the future electricity market price absent the electrical production of the PV system.

$$E_{PVc} - E_{PVp} = 0$$

To solve for IRR the equation for $\boldsymbol{E_{PVp}}$ is subtracted from $\boldsymbol{E_{PVc}}$ and the difference is set to equal zero. All variables, with the exception of the interest rate, are held constant for the case being considered and the equation is solved for the interest rate, *i*, by successive approximation.

3. 1MW PV SYSTEM EXAMPLE

For our example case we simulated the performance of a hypothetical 1MW photovoltaic system installed in Santa Clara, California (Latitude = 37.35 N, Longitude = 121.96 W). We then ran eight financial scenarios varying only the rate of increase in the annual electricity price and the level of aggregate secondary market characteristics on a per kilowatt hour basis. For each scenario we solved for the internal rate of return.

3.1 Example 1MW System Assumptions

--PV system size is 1MW STC dc
--Average inverter efficiency is 0.92
--PV energy production degradation = 0.5% per year
--Tilt = latitude; azimuth = true south; no shading.
--PV useful life assumed to be 30 years
--End of life decommissioning cost = end of life salvage price (and no hazmat liability or that liability is assumed by product manufacturers).

A simulation based upon these parameters yields an annual energy production of 1,445,864 kWh (1,445MWh) or 43,376MWh over its lifetime. These values can be calculated using the National Renewable Energy Laboratory's PV Watts online calculator by applying the default parameters [4]. It can also be verified using the commercial simulation program such as *PV DesignPro* or RETScreen tool set [5, 6].

We assumed an installed cost of $6.50/W for a full cost, before incentives, of $6,500,000. We also assumed a grant of $2.80/W yielding total of $2,800,000 in buy down [7]. In addition we assumed the value of the ITC to be 30% applied to the full installed cost of the system, or $1,950,000 [8]. No allocation was made for accelerated depreciation. The combined first cost subsidies bring the total first cost of the 1MW PV system in our example to $1,750,000.

3.2 IRR Simulations

We have applied the physical and financial assumptions listed above to the IRR model for investment in a PV system. We then manipulated two parameters: annual increase in the cost of electricity in dollars per kilowatt hour and secondary market characteristics in the form of a performance based incentive in dollars per kilowatt hour. The secondary market characteristics were alternated, somewhat arbitrarily, between a value of $30/MWh and $60/MWh over the full life of the system. The results are shown in Table 1 below.

TABLE 1: SIMULATION SCENARIO VALUES

Case	**ΔElec Price**	**SMC**	**IRR**
#	($/kWh/year)	($/kWh)	(%)
1	0.005	0.03	**16.82**
2	0.005	0.06	**19.15**
3	0.010	0.03	**18.81**
4	0.010	0.06	**20.96**
5	0.015	0.03	**20.51**
6	0.015	0.06	**22.55**
7	0.020	0.03	**22.02**
8	0.020	0.06	**23.97**

4. RESULTS

The eight simulation scenarios demonstrate, albeit simplistically, that increases in the market price of electrical energy, over the productive life of the PV system, will, given the conditions specified above, increase the internal rate of return of an investment in that photovoltaic system. In addition, the presence of future secondary market characteristics, such as renewable energy certificates, carbon credits, solar renewable energy credits, feed in tariffs and the like, will also increase the PV system investor's internal rate of return.

On a more heuristic level, this model graphically illustrates the linkage between the present value of a PV system cost (installed cost) and the present value of the price of PV energy which will be generated over the life of the system. Unlike other approaches, such simple payback, this analysis models the full financial behavior of a modern photovoltaic system over its productive life. It accurately reflects the physical features of the technology –such as system longevity-- and the energy market in which its output participates. The analytical approach used in this paper can be applied to any renewable energy -- zero fuel cost – system. It provides the basis for comparison of an investment in a renewable energy system with other investment opportunities.

The limitations of the model, at this point, are significant. This is an extremely simplified analysis. Changes in the market price of electricity have been represented only as increasing and linear. The two cases of secondary market characteristics, aggregate values of $30 and $60 per MWh, have been represented as fixed over the full thirty years life of the PV system. It is highly unlikely that whatever market conditions the future holds they will be as uniform and well behaved as in these examples. The model developed in this paper addresses a single, highly constrained configuration. Given a different set of physical and financial constraints, such as a utility scale PV installation supplying power to the gird at the wholesale rate, the model would be substantially different.

5. CONCLUSIONS

To make the economic case for an investment in photovoltaic technology it is imperative to lower first costs (installed cost) as much as possible. Historically the key driver for this objective is the reduction of module costs. The ability to maintain system performance is critical from the perspective of preserving the generating capability of the system and extending its useful life, however the associated costs are not major influences on PV energy cost, and thus on the IRR.

Secondary market characteristics play an important role in determining the final value proposition. However, as these are subject to public policy considerations, they can vary widely from year to year and from location to location. Even cursory review of renewable energy public policy in the United States in the last ten years graphically illustrates the variability of these factors. Depending upon the events of the day or the decade they will be more or less present and will likely be difficult, if not impossible, to anticipate more than one or two political cycles into the future.

The market price of conventional energy, while it too may be heavily influenced by government policy, is ultimately a product of markets, which in turn are defined by world demand for fuel, by global politics, and ultimately by geology. An investment in a photovoltaic system represents a calculated risk/opportunity, with potential hazard and rewards. By identifying the linkage between PV energy cost and future PV energy price this model gives the potential investor a tool to analyze and manage financial risks and benefits.

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7. REFERENCES

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