# A Simple Method for Consumers to Address Uncertainty When Purchasing Photovoltaics

Dr. Thomas E. Hoff
Clean Power Research
10 Glen Ct.
Napa, CA 94558
www.clean-power.com

Dr. Robert Margolis
National Renewable Energy Laboratory
901 D Street, SW, Suite 903
Washington, DC 20024

Christy Herig
Segue Consulting
17609 First St. E.
Redington Shores, FL 33708
www.nrel.gov

## Executive Summary

Investment under uncertainty is a complex subject and has been the focus of much research. Financial tools, real options, decision analysis and other approaches quantify the uncertainty based on market data and/or the decision maker's beliefs and the investment decision is made within this context.

It is difficult to identify all uncertainties and solicit the decision maker's beliefs about them. An alternative is to identify the minimum set of beliefs a decision maker needs to have in order to invest in a given technology. This enables a decision maker to have confidence in their decision based on a few key issues.

This paper examines the consumer's decision to invest in photovoltaics (PV). It concludes that consumers are economically better off investing immediately than waiting if: (1) the system has positive economic value; (2) PV prices will decline less than X% per year; and (3) electricity rates will decline less than Y% per year where X and Y are customer- and location-dependent. For example, a residential consumer in San Jose, CA needs to believe that PV prices will decline less than 7 percent per year and electric rates will not drop more than 20 percent in order to justify purchase of a 5 kW PV system that satisfies half of their electricity needs.

## Background

There is a growing interest among individuals and companies in considering distributed resources as an alternative to conventional utility electric supply. These resources include enhanced energy efficiency, photovoltaics (PV), fuel cells, gas turbines, etc. Motivated by a desire to reduce utility bills and to help the environment, consumers want to know if these alternatives are good investments.

While one could evaluate all alternatives, this paper limits the analysis to an investment in PV. This is done for the following reasons:

- It simplifies the analysis, thus providing a better facilitation of the meaning of the results
- An important competitor is energy efficiency and it is assumed that all efficiency investments have already been made
- PV is the simplest commercially available technology to own and operate and thus is likely to become more widely available than some of the other technologies
- PV is the only commercially available distributed generation technology that provides consumers with relative certainty in their future electric prices because it does not use fossil fuels

## Introduction

When evaluating a market investment such as a stock or bond, the price that one should be willing to pay is the same for everyone regardless of where they live and the details of their personal circumstances. In addition, the market price is unaffected by the purchase of any one investor on the scale at which most individuals purchase stocks and bonds. Furthermore, these investments are not mutually exclusive and are only limited by the amount of money a person wants to invest.

Customer-owned PV systems, however, differ from stocks and bonds in several ways. There is the obvious difference that an investment in PV is an investment in property that depreciates over time while the value of stocks and bonds is expected to increase over time. Beyond this basic difference are the following differences:

1. The price a consumer should be willing to pay is situation-dependent. This is because incentives, electricity prices, solar resource, and current energy consumption differ by location and customer.
2. The price a consumer should be willing to pay for future investments in PV is based on past PV investments because the PV investment opportunity is depletable. That is, a particular consumer has a limited amount of PV they can purchase before the marginal electricity savings value goes to $0.[1] The option of purchasing a PV system is lost for the future by purchasing a PV system now.

[1] This is magnified in areas with tiered rate structures (such as California) where the value of the first kW can be substantially higher than the value of additional kWs.

3. An investment that reduces costs requires a different analytical treatment than an investment that produces revenue. This is because delaying the purchase of a PV system results in the loss of cost savings (i.e., reduced utility bills).

# Assumptions

## Sample Customer

A sample consumer is used throughout this paper in order to provide concrete results. The consumer has the characteristics as presented in Table 1.

Table 1. Characteristics of sample customer.

| | |
|---|---|
| Location | San Jose, California |
| Customer Type | Residential |
| Annual Utility Bill | \$2,650[2] |
| PV System Cost | \$8,000/$kW_{DC}$ (before incentives) |
| PV System Life | 30 Years |
| Payment Method | Loan w/ tax-deductible interest |
| Loan Terms | 30-year, 7% loan |

## Analytical Tool

The Estimator (also referred to as the Clean Power Estimator)[3] is used to perform the analysis. The Estimator is an Internet-based computer program, designed to help customers evaluate the cost-effectiveness of clean energy systems such as photovoltaic (solar electric), solar thermal, wind, and efficiency investments. It provides a personalized estimate of the costs and benefits of a system for a specific residential or commercial customer and takes into account the characteristics of the specific customer purchasing the system in order to provide the most relevant analysis. These customer characteristics may include the type of system being purchased as well as the customer's location, rate structure, tax status and other information.

The National Renewable Energy Laboratory (NREL) has funded the development of a version of the Estimator to perform market and policy analysis. It is called the Market and Policy Analysis tool. The Market and Policy Analysis tool is used in this paper to perform the analysis.[4]

## Investment Criterion

The financial community often uses net present value (NPV) as the standard economic framework to make investment decisions. NPV is the sum of the discounted cash flows over the life of the project. The typical test is that the investment is a good one if the

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[2] the \$2,650 annual bill is selected because the consumer can satisfy all their needs with a 10 $kW_{DC}$ system
[3] More information is available about the Clean Power Estimator at www.clean-power.com.
[4] The tool can be used accessed at www.clean-power.com/nrelpv.

NPV is greater than $0. This paper will show that, while this is a necessary condition, it is not a sufficient condition.

## Critical Inputs

The first step in the analysis is to identify inputs that have the greatest effect on the economic value. Consider changes to the following inputs: cost, electric rates, PV output, and interest rate. Figure 1 presents the change in net present value for the sample customer with parameter changes of ± 50 percent. The figure suggests that increasing electric rates (or PV output) is comparable to decreasing cost, while interest rate changes have a lower impact.

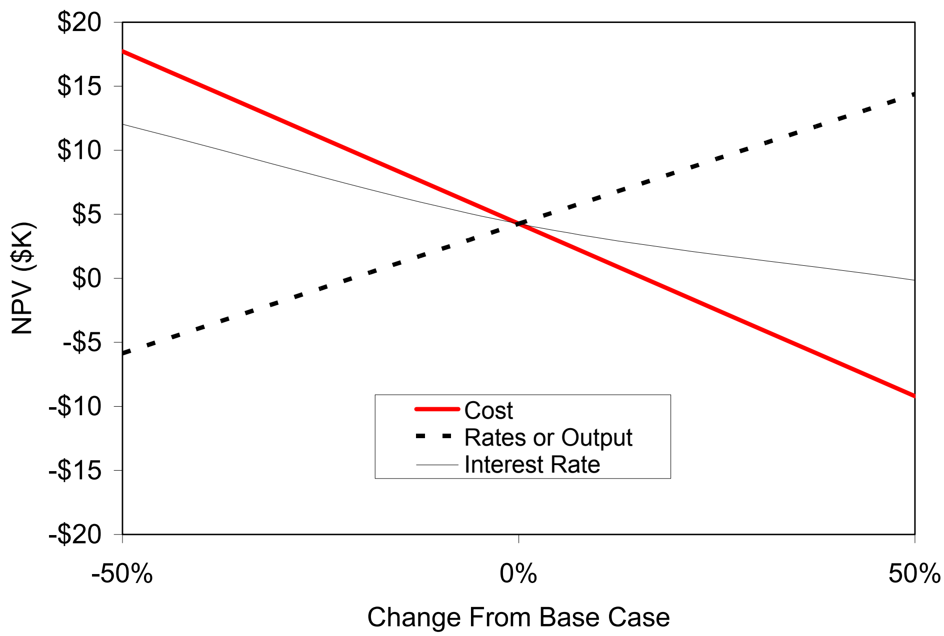


Figure 1. Sensitivity of net present value to input assumptions (based on 5 kW PV system for sample customer presented in Table 1).

Uncertainties that are of the most concern from the consumer's perspective are the ones that have the largest economic effect and the ones to which consumers are unable to respond. Consider the four uncertainties listed above: cost, electricity rates, system output, and interest rates.

PV system output is very closely related to equipment performance and equipment performance is covered by system warranties. It is assumed that the warranty is written such that consumers have sufficient confidence that performance is of concern primarily to the party offering the warranty rather than the consumer. In addition, while interest rates may change over time, a consumer could respond to interest rate declines by refinancing their PV system in the same way that they would refinance their house.

The remaining two critical uncertainties are the net system cost after incentives and electricity rates. These uncertainties have a large economic effect and cannot be mitigated by future actions. The consumer must decide whether to invest immediately or to wait to invest with the hope that the net cost will decrease significantly (due to technological breakthroughs, general price reductions, or changes in incentive programs). Similarly, the consumer must also decide whether they believe that electricity prices will increase or decrease in the future.

## Consumer Decision

Consumers considering an investment in PV must contend with a variety of decisions and uncertainties. At a broad level, purchasing PV means not purchasing other distributed resources, including ones that are currently available (such as energy efficiency measures that they have not implemented) as well as ones that might be available in the future (such as residential fuel cells, etc.). In addition, there are uncertainties about the cost and value of the PV system. For the reasons stated earlier, this paper focuses only on the PV investment.

As stated above, a standard economic criterion is to invest when the net present value is positive. It is necessary that the NPV of an investment in PV exceeds $0 in order for the investment to be a good one. It is not sufficient, however, because one may not obtain the same value from purchasing a unit of PV now and then purchasing another unit of PV later.

As a result, rather than answering the question, "Should I purchase a PV system?" consumers are faced with the following question: "How much PV should I purchase and when should I make the purchase?" That is, do they purchase any PV now or do they wait until later (perhaps indefinitely)?

Figure 2 presents a simplified description the consumer's decision: buy now or wait. If they buy now, they face the possibility of electric rates going down (but there is no decision to make even if this occurs). If they wait, they face the possibility of electric rates increasing and costs increasing as well.

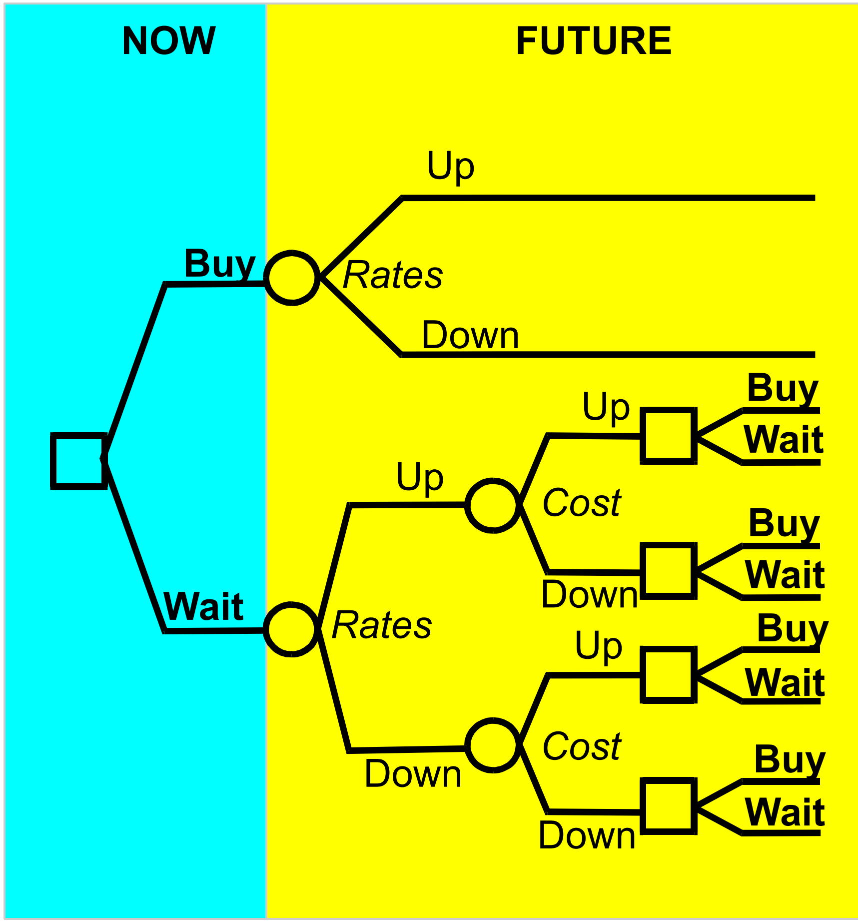


Figure 2. Consumer Decision.

## Problem Formulation

The problem can be formulated mathematically as follows. The consumer's objective is to purchase the optimal amount of PV over time such that the expected NPV of the investment stream (i.e., PV can be purchased incrementally over time) is maximized. Since NPV equals the sum of the discounted value minus cost, this is mathematically formulated as:

$$\max_{PV_0, PV_1, \ldots PV_L} E\left[\sum_{t=0}^{L} \frac{\tilde{V}_t\left(\sum_{n=\max(t-S,0)}^{t} PV_n\right) - \tilde{C}_t(PV_t)}{(1+r)^t}\right] \qquad (1)$$

Consider the meaning of each term in Equation ( 1 ). $\max_{PV_0, PV_1, \ldots PV_L}$ means that the investor wants to select the PV system size in year t ($PV_t$) such that result is maximized. $E$ corresponds to the fact that the consumer is an expected value decision maker.[5] $L$ represents the number of years that the consumer expects to live (while this is uncertain

[5] The problem is further complicated if the consumer is an expected utility decision maker.

in reality, it is assumed to be known with certainty; in addition, consumers that treat cost and value the same for future generations could substitute *L* with infinity). $\tilde{V}_t$ is the value function and $\tilde{C}_t$ is the cost function at time *t*. The squiggly line over *V* and *C* denote the fact that value and cost are uncertain. The value function in year t, depends upon the total amount of PV installed to date excluding PV investments made in earlier years that are no longer active (i.e., $\sum_{n=\max(t-S,0)}^{t} PV_n$ , where *S* is the life of the PV system). The value function may also depend upon other factors, such as electricity prices, tax effects, etc. Cost is the net cost after incentives.

This is what Equation ( 1 ) would look like for years 0, 1, and 2 of the investment. The *E* is outside the square bracket because it is the expectation over future uncertain cash flows.

$$\max_{PV_0, PV_1, \ldots PV_L} \left\{ V_0(PV_0) - C_0(PV_0) + E\left[ \frac{\tilde{V}_1(PV_0 + PV_1) - \tilde{C}_1(PV_1)}{(1+r)} + \frac{\tilde{V}_2(PV_0 + PV_1 + PV_2) - \tilde{C}_2(PV_2)}{(1+r)^2} + \cdots \right] \right\}$$

It may be difficult to solve Equation ( 1 ) because of the uncertainty and shape of the functions. Thus, in order to simplify the analysis, assume that

- cost is proportional to the amount of PV installed;
- value is proportional to the amount of PV installed up to a certain point and then 0 after that (this implies that rate structures are flat); and
- value is constant over time (this implies that future electricity prices are known with certainty and that the consumer's energy consumption is constant over time).

Mathematically, this means that

$$\tilde{C}_t(PV) = c_{unit-t} PV$$

$$\tilde{V}_t(PV) = v_{unit} PV \text{ for } PV \le PVMAX$$
$$= 0 \quad \text{for } PV > PVMAX$$

where PVMAX is the maximum amount of PV a particular customer can purchase and still have a non-zero marginal value; i.e., there is a limit to the amount of on-site power a particular customer can produce.

Substitute these assumptions into Equation ( 1 )and simplify.

$$\max_{PV_0, PV_1, \ldots PV_L} \sum_{t=0}^{L} \frac{\sum_{n=\max(t-S,0)}^{t} v_{unit} \times PV_n - c_{unit-t} \times PV_t}{(1+r)^t}$$

regrouping the value terms,

$$\max_{PV_0, PV_1, \ldots PV_L} \sum_{t=0}^{S} \frac{\left[ \sum_{m=0}^{S} \frac{v_{unit}}{(1+r)^m} - c_{unit-t} \right] \times (PV_t)}{(1+r)^t}$$

and applying the definition of net present value

| | |
|---|---|
| $\max_{PV_0, PV_1, \ldots PV_L} \sum_{t=0}^{L} \frac{NPV_{unit-t} \times (PV_t)}{(1+r)^t}$ | ( 2 ) |

The optimum solution to this linear equation is that either the full amount of PV (PVMAX) will be installed at a single point in time or no PV will be installed at all. That is, one calculates the NPV at each point in time and selects the time to invest where the present value of $NPV_t$ is maximized.

## Point of Indifference

As stated earlier, the consumer's decision is to purchase now or to wait. Since the solution to Equation ( 2 ) is to fully invest at a single point in time (or to not invest at all), consumers have a point of indifference between investing now or waiting. The consumer's decision is depicted in Figure 3.

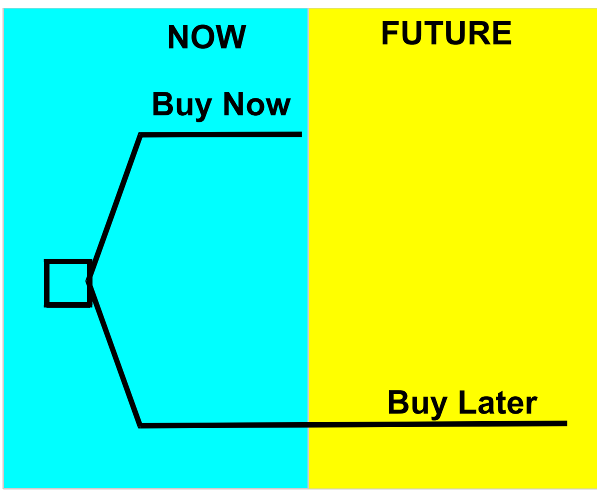


Figure 3. Consumer decision.

Suppose that the decision is to purchase now or to purchase in T years. The consumer is indifferent between purchasing now or waiting if the NPV of purchasing immediately equals the NPV of purchasing in T years.[6] That is, the consumer is indifferent if

[6] The true point of indifference would take into account the value of the option that the consumer has to invest in the future after the initial PV system wears out. This will make the NPV of the current investment opportunity even more valuable.

| | |
|---|---|
| $NPV_0 = \frac{NPV_T}{(1+r)^T}$ | ( 3 ) |

where $NPV_0$ is the net present value of an investment in year 0, $NPV_T$ is the net present value in year T of an investment made in year T. (Note: since the $NPV_T$ occurs in the future, it must be discounted to year 0 to make it comparable with $NPV_0$. The reason for this is that, by waiting to invest, the consumer loses the opportunity to reduce their utility bill for the next T years. In order to make up for this missed opportunity, the NPV of the investment must be higher in the future than it is today.)

## *Simple Example*

Suppose that the sample customer is trying to decide whether to purchase a 5 $kW_{DC}$ PV system now for $40,000 or wait 10 years until the price comes down. The California Energy Commision's PV buydown of $3,800/$kW_{AC}$ and 15% California state income tax credit are currently available. It is assumed that there will be no incentives in 10 years.

Using NREL's Market and Policy Analysis tool,[7] the incentives reduce the $40,000 system cost to a net cost of $21,189 to the consumer. The NPV of the investment is $4,263. As shown by the solid black line in Figure 4, the customer pays $2,212 in the first year ($1,033 utility bill plus $1,692 loan payment minus $512 in income tax savings due to loan interest write-off) as compared to their current utility bill of $2,650, thus saving $438 in the first year.

Should this customer purchase the system now or wait 10 years? Equation ( 3 ) can be used to determine how much the system could cost in 10 years and the customer be economically indifferent between purchasing now or waiting.[8] Assuming a 7% discount rate, the NPV of the investment in year 10 would have to be $8,385 in order for the consumer to be economically indifferent between investing now and waiting because $\$8,385/(1.07)^{10} = \$4,263$.

Should this customer purchase the system now or wait 10 years? NREL's Market and Policy Analysis tool indicates that a 5 $kW_{DC}$ system must cost $16,000 without incentives to result in a NPV of $8,385. The dashed red line in Figure 4 presents the utility bill and after-tax loan payments associated with this alternative ($2,650 for the first 10 years followed by the reduced cost in subsequent years).

[7] The tool is available at http://www.clean-power.com/nrelpv
[8] This is a very conservative criterion because the consumer will have the opportunity to invest in PV again in 30 years when the existing system needs to be replaced.

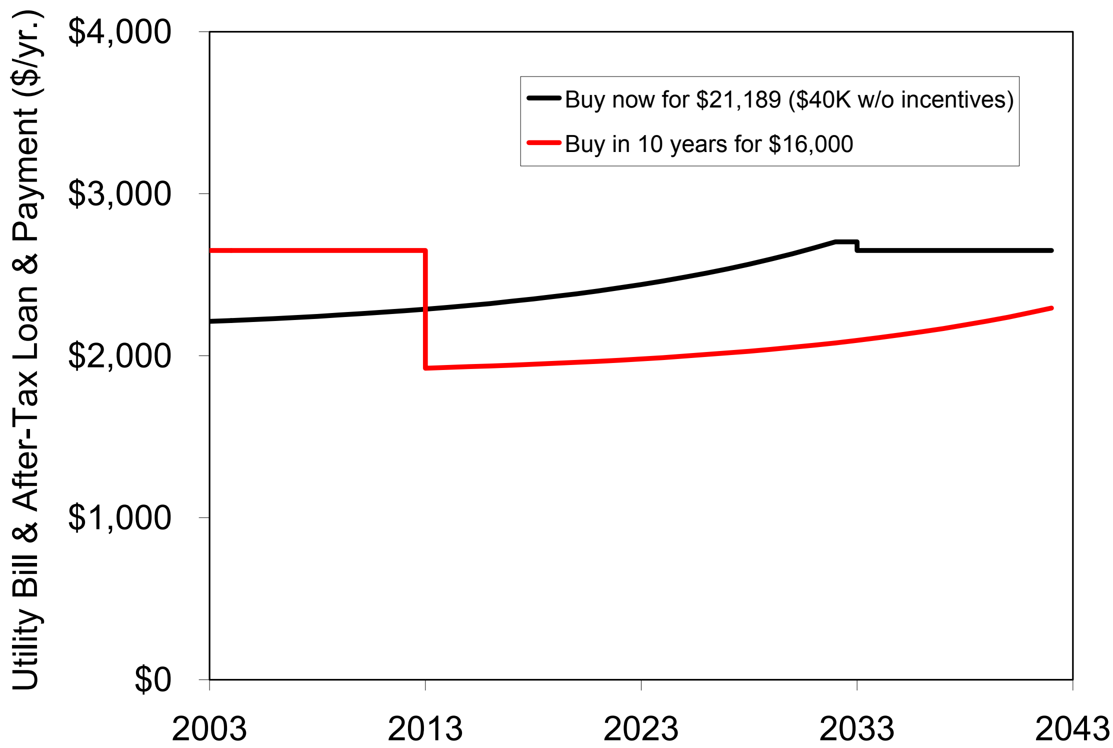


Figure 4. Example of purchasing a PV system now versus waiting 10 years.

Figure 5 helps to illustrate why a consumer is economically indifferent between these two alternatives. The light red and black lines are the discounted costs for the corresponding buy now and wait 10 year decisions. The decision to buy now saves money for the first 10 years while the decision to wait 10 years saves money beginning in 2013. As can be seen visually in the figure, the area of the Buy in 10 years minus Buy now for the first 10 years is approximately equal to the area of the Buy now minus Buy in 10 years for the next 30 years. This makes the consumer economically indifferent between the two alternatives.

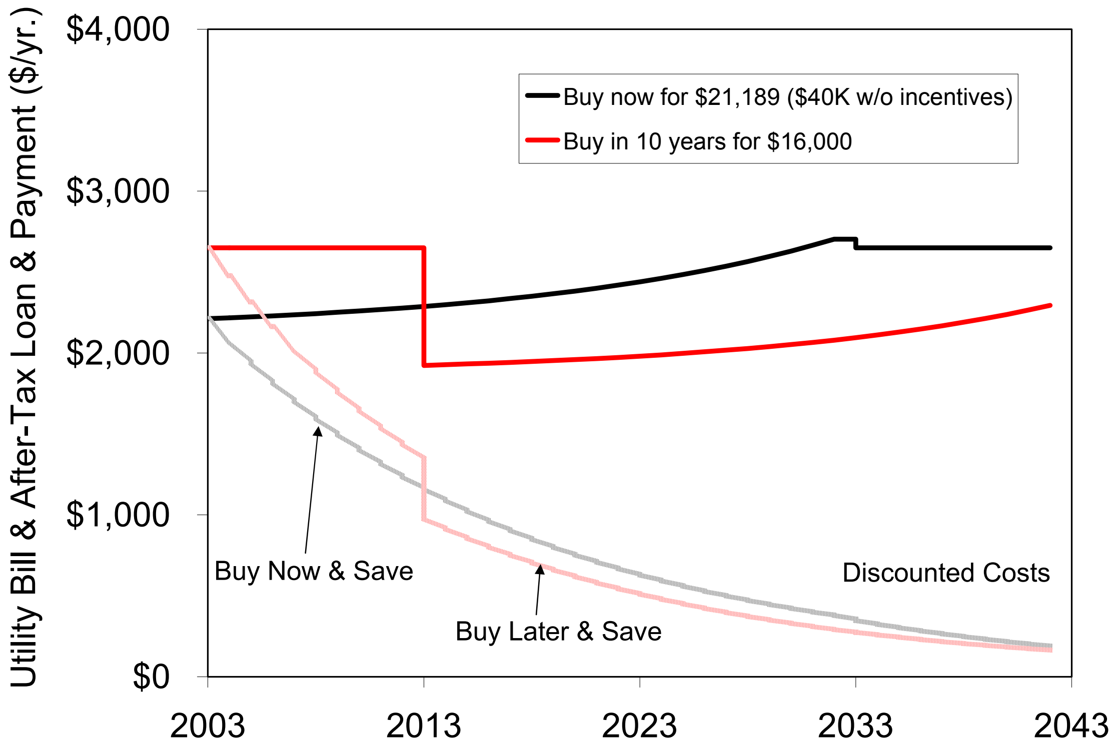


Figure 5. Example of purchasing a PV system now versus waiting 10 years (Discounted).

**Discussion**

The preceding analysis suggests that a consumer is economically indifferent between purchasing a $40,000 PV system today ($21,189 after incentives) or waiting 10 years and purchasing a system for $16,000 with no incentives. PV would have to reduce in price 9 percent every year for the next 10 years in order for this scenario to occur. The consumer only needs to believe that PV system prices will decrease less than 9 percent per year in order to be better off investing immediately versus waiting 10 years.

## *Extension of Simple Example*

The previous section simplified the decision to either investing immediately or waiting 10 years. In reality, the consumer could invest at any time during which a variety of incentive combinations could occur. This section expands the simple example to demonstrate how much the price of PV must decrease in order for the consumer to be better off waiting to invest over the next ten years under a variety of incentive scenarios. A combination of three scenarios are evaluated for each year: CEC buydown only; buydown plus 7.5% state tax credit; and buydown plus 15% state tax credit.

**Breakeven NPV**

The investment decision is based on the NPV. As discussed in the previous section, the NPV must increase over time in order for the consumer to wait to invest. Assume that all the details are the same as in the simple example. Table 2 presents the NPV that the customer must obtain in order to be economically indifferent between investing and waiting.

Table 2. Required NPV to be Economically Indifferent (2003 – 2013).

| | Breakeven NPV |
|---|---|
| 2003 | $4,263 |
| 2004 | $4,561 |
| 2005 | $4,881 |
| 2006 | $5,222 |
| 2007 | $5,588 |
| 2008 | $5,979 |
| 2009 | $6,398 |
| 2010 | $6,845 |
| 2011 | $7,325 |
| 2012 | $7,837 |
| 2013 | $8,386 |

**CEC PV Buydown**

CEC buydown for systems under 30 kW was $4,000/kW_{AC}$ in the first half of 2003 where the definition of a $kW_{AC}$ is the module at PVUSA test conditions multiplied by peak inverter efficiency. According to the CEC's Emerging Renewables Program Guidebook,[9] the rebate levels will be reduced by 20 cents per watt every six months beginning July 1, 2003 (and every January 1st and July 1st thereafter). The declining buydown schedule is shown in Table 3. Note that, given the budget uncertainty in California and the speed at which rebate applications are occurring, the rebate could reduce at an even faster rate than is presented in the table. This uncertainty is not included in the analysis because it will simply further early investment rather than waiting.

[9] Available at http://www.energy.ca.gov/renewables/guidebooks/500-03-001F.PDF. See page 9.

Table 3. California Energy Commission PV Buydown (Jul. 2003 – 2013).

| | CEC Buydown ($/kW$_{AC}$) |
|---|---|
| 2003 | $3,800 |
| 2004 | $3,400 |
| 2005 | $3,000 |
| 2006 | $2,600 |
| 2007 | $2,200 |
| 2008 | $1,800 |
| 2009 | $1,400 |
| 2010 | $1,000 |
| 2011 | $600 |
| 2012 | $200 |
| 2013 | $0 |

**California State Tax Credit**

A California state tax credit is available to residential consumers. According to the California Solar Center, "the tax credit, for tax years 2001-2003, is equal to the lesser of 15 percent of the net purchase cost of a photovoltaic or wind-driven system with a generating capacity of not more than 200 kilowatts. The Bill allows a credit for one system per each separate legal parcel of property or per each address of the taxpayer in California, and requires recapture of the credit if the system is sold or removed from California within one year. The credit will be reduced to half that amount for tax years 2004-2005, and will sunset on January 1, 2006."[10]

The credit, however, faced intense scrutiny and was almost cancelled during last year's budget proceedings. The budgetary situation of California is even worse this year. While there is currently a predictable decline in the tax credit, there is the possibility that the tax credit could be repealed entirely. Thus, the tax credit could range between 0% and 15%.

**Results**

Return to the sample customer. As shown in Table 2, the NPV of this system assuming no rate changes is $4,263. This customer would need to obtain an NPV of $4,561 in 2004 in order to be indifferent between investing and waiting. This is because $4,561 discounted at a 7% discount rate equals $4,263.

Thus, suppose that the CEC buydown program is reduced as planned (from $3,800/kW in the second half of 2003 to $3,200/kW in July 2004) and that the tax credit is reduced from 15% in 2003 to 7.5% in 2004. How much can a 5 kW system cost in July 2004 for the consumer to obtain an NPV of $4,561? Using NREL's Market and Policy Analysis

[10] Available at http://www.californiasolarcenter.org/legislation.html.

tool, obtaining an NPV of $4,561 requires that the system costs $36,500. This is a $3,500, or almost 9% cost reduction from the current price of $40,000.

This process was repeated for all scenarios. The red circles in Figure 6 are the required cost reduction with the CEC buydown, the green circles are the required cost reduction with the buydown and a 7.5% state tax credit, and the blue circles are the required cost reduction with the buydown and a 15% state tax credit. The black circles show the expected path based on what is planned for existing incentives.

The shaded area is included for reference purposes to show what historical price reductions have been. The high reduction corresponds to the price reductions experienced in the Japanese residential market from 1997 to 2001[11] and the low reduction is a 3% rate. The average price reduction in modules over the past 25 years has been about 5% per year.

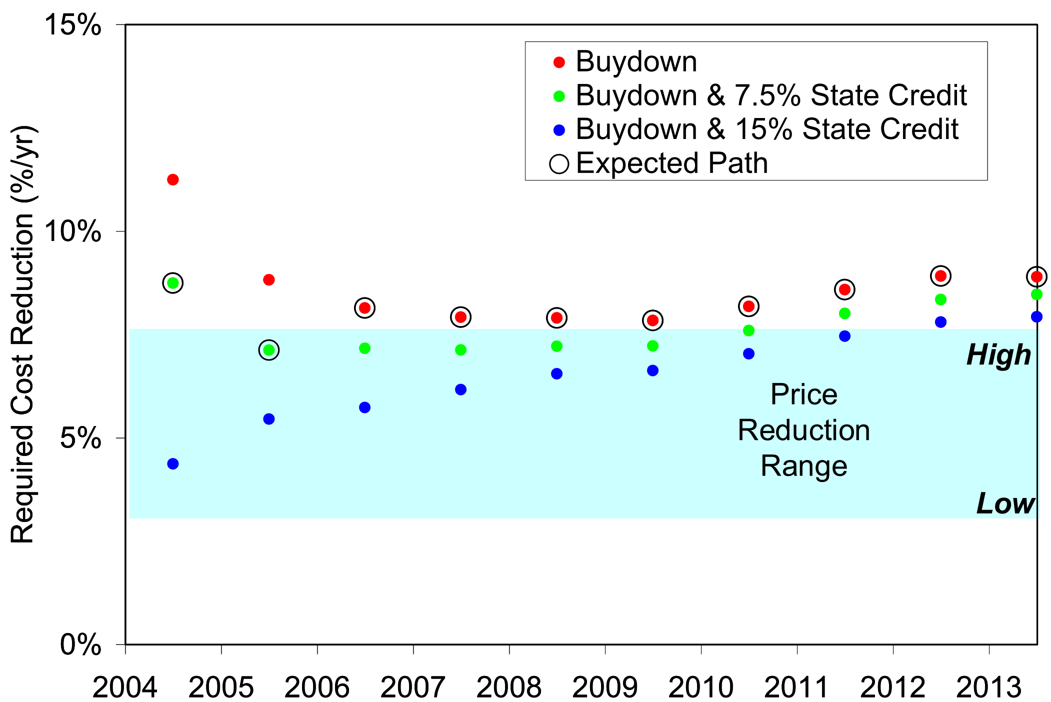


Figure 6. Required cost reductions to delay investment (San Jose, CA residential customer that meets half their energy needs with 5 $kW_{DC}$ PV system).

## Discussion

Consumers can use Figure 6 to determine what they need to believe in order to invest immediately based on what scenarios they believe are feasible. For example, suppose the

[11] Based on information provided courtesy of BP Solar.

consumer believes that the incentive will follow the expected path (colors with black circles). Except for 2005, the consumer should invest now unless they believe that prices will decline faster than 7 ½ percent per year over the next decade (i.e., the high rate experienced by the Japanese program). The figure shows that consumers are better off investing now than waiting in many cases.

**Note**

While the focus of this paper is on investments from the consumer's perspective, it should also be noted that this analysis is beneficial in designing good incentive programs. In particular, the two criteria that a well designed incentive program must meet are:

1. The NPV is positive (so the consumer is better off investing than not investing)
2. Consumers are better off investing immediately than waiting relative to their expectations about future PV prices.
3. The incentive should be structures to reduce to $0 at the time when systems are projected to be economical in that location without incentives.

# Electricity Price Uncertainty

The first section of this paper addressed the issue of how consumers should make investment decisions in the face of PV price uncertainty. This section addresses the issue of electricity price uncertainty.

## *Introduction*

Risk is a broad and complex topic. Many corporations have risk management departments that use a variety of risk mitigation and evaluation tools. Some of these tools include:

- Financial tools, such as options, futures, forward contracts, and swaps
- Portfolio analysis
- Real options
- Decision analysis
- Scenario analysis

An important assumption upon which these tools are based is that there is either an implicit or explicit understanding of the potential uncertainties. The financial tools rely on markets and an understanding of the uncertainty processes to price risk. Portfolio analysis relies on market conditions (but has also been applied to electric generating portfolios). Real options and decision analysis rely on the user's belief about the future, both in terms of what the uncertainty might look like as well as the probabilities of the various occurrences. Scenario analysis relies on the user's belief about the future but does not require probabilities of the various possible states of the world.

Use of these tools requires an understanding of the uncertainty. In order to apply many of these tools to electricity rate uncertainty, however, one needs to understand the uncertain process that the rates could follow as well as being able to assign probabilities to the various states of the world.

This may be a difficult task when it comes to electricity prices. While electricity prices do not tend to be volatile over the short term (e.g., days), changes can be complex and can occur in a variety of ways. Some of the changes may have been predictable while it would have been very difficult to predict some of the rate structure changes.

- Change could occur to the rate structure components, including energy prices by month, period, or tier, demand changes by month, period, or tier, fixed costs, minimum bills, bill discounts, fuel adjustment costs, etc.
- The change could occur suddenly or gradually over time
- Rates could increase or decrease
- The entire rate structures could change (e.g., residential customers in California moved from a 2-tier to 5-tier rate structure in 2001; low-tier users experienced no change in their monthly electric bill while some high users saw their bills double overnight)

## Approach

The same way that the first part of the paper determined how much PV prices must decline in order to wait, one can determine how much rates can decrease and the consumer still be better off investing than not investing. The analysis is somewhat different in this case. The key question is to determine how much of a rate change the consumer can tolerate and be better off investing than not investing. The criterion is that the NPV remain greater than zero.

As stated earlier, rate changes can occur in a variety of ways and at different times. The two extremes considered in this analysis are where all portions of the rate structure have an immediate, one-time shift and the other is a change that occurs at an annual rate over the life of the PV system.

The objective is to determine how much a rate change the consumer can tolerate and still be better off waiting than investing.

### Simple Example

Consider once again to the simple example of the San Jose, CA residential customer with a 5 kW system. The NPV of this system with current rates is $4,263. Using the NREL's Policy Analysis Tool, an immediate 21 percent rate decrease or an annual decrease of 2½% would result in an NPV of $0. Thus, if the consumer believes that any change in rates will occur immediately and that change will be less than a 21 percent decrease, they are better off investing now rather than waiting.

### System Size

Due to the fact that the energy value of the PV system is a function of its size in a location with tiered rates, a further complication that needs to be considered is the effect of system size on the allowable rate change. Figure 7 and Figure 8 present the allowable rate change versus system size. Figure 7 presents the results for an immediate, one-time rate change. Figure 8 presents the results for an annually occurring change. For example, the figures suggest that a consumer purchasing a PV system that provides 20 percent of their needs could tolerate an immediate rate decrease of 25 percent or an annual rate decrease of 3 percent per year. As long as the consumer believes that the rates will decrease by no more than this amount, they are better off investing now than later.

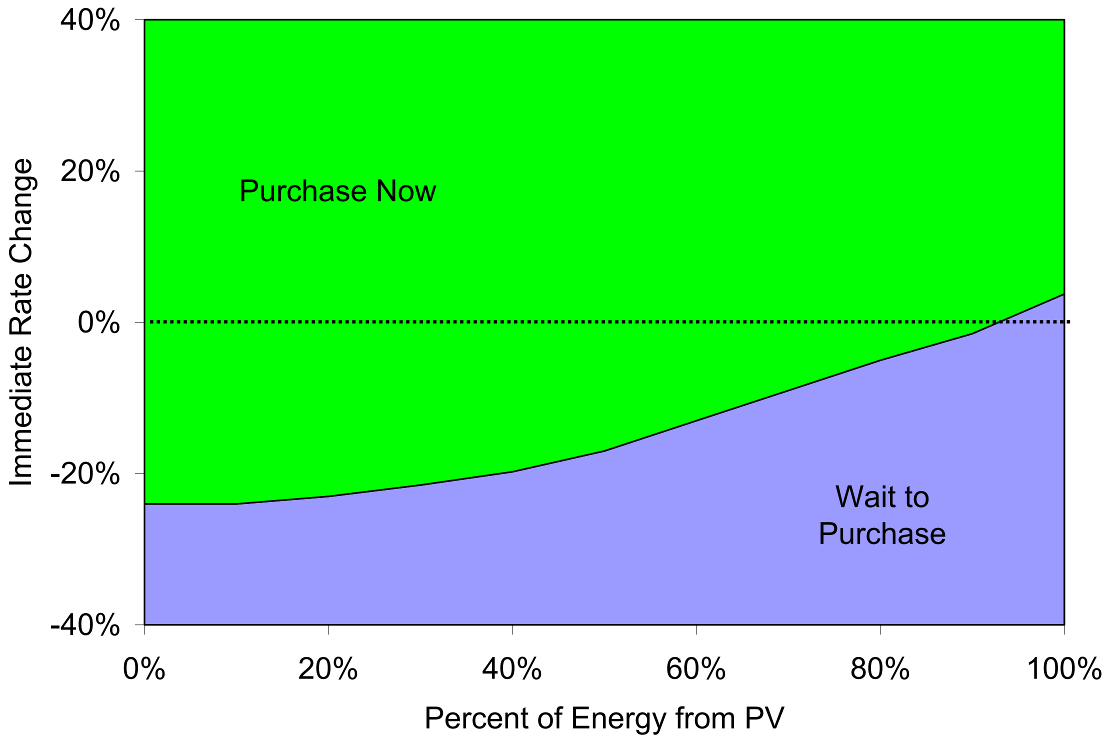


Figure 7. Allowable immediate, one-time rate change.

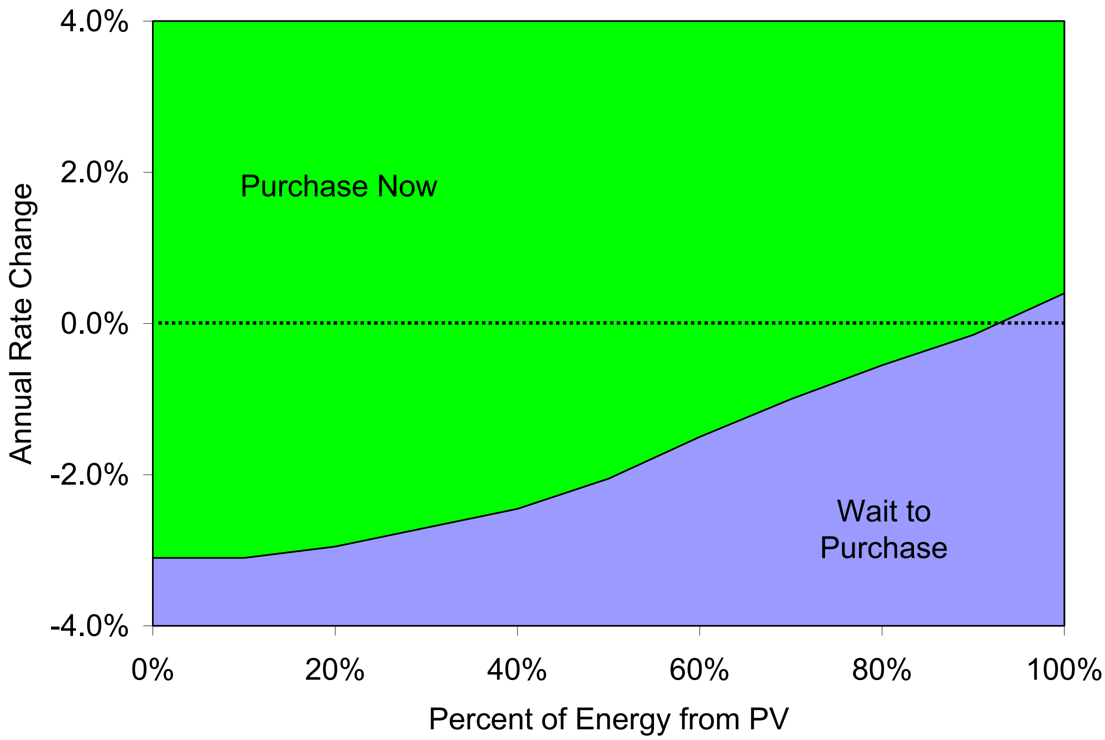


Figure 8. Allowable annual rate change.

## Conclusions

Investment under uncertainty is a complex subject and has been the focus of much research. Financial tools, real options, decision analysis and other approaches quantify the uncertainty based on market data and/or the decision maker's beliefs and the investment decision is made within this context.

It is difficult to identify all uncertainties and solicit the decision maker's beliefs about them. An alternative is to identify the minimum beliefs a decision maker needs to have in order to invest. This enables a decision maker to have confidence in their decision based on a few key issues.

This paper examines the consumer's decision to invest in photovoltaics (PV). It concludes that consumers are economically better off investing immediately than waiting if: (1) the system has positive economic value; (2) PV prices will decline less than X% per year; and (3) electricity rates will decline less than Y% per year where X and Y are customer- and location-dependent. For example, a residential consumer in San Jose, CA needs to believe that PV prices will decline less than 7 percent per year and electric rates will not drop more than 20 percent in order to justify purchase of a 5 kW PV system that satisfies half of their electricity needs.