Economic and Policy Evaluation of Solar Energy for Indiana Business and Residential Applications

Jinho Jung (jung104@purdue.edu) and Wallace E. Tyner (wtyner@purdue.edu)

Department of Agricultural Economics
Purdue University

Selected Paper prepared for presentation at the 2015 Agricultural & Applied Economics Association and Western Agricultural Economics Association Annual Meeting, San Francisco, CA, July 26-28

1. Introduction

Solar energy has been expanding in the U.S. and globally recently, as have other renewable energy sources such as wind, hydro, and biomass. Solar energy is clean in the sense that it is free from carbon and other emissions related to burning fossil fuels and sustainable because the sun does not deplete any natural resources. The expansion may partly be attributed to policies encouraging its adoption. Furthermore, solar energy can easily be installed by individual consumers at a relatively small-scale and may be less expensive than electricity from grids under certain conditions. Indiana is also expanding solar energy with other renewables to protect its environment because 95% of electricity is generated from coal (U.S. Energy Information Administration (U.S. EIA), 2014). Due to the infancy of the technology, however, there has been little information for citizens who consider adopting solar PV systems in homes and farm businesses in Indiana. Thus, we are interested in evaluating the economics of solar photovoltaic (PV) systems installed in individual homes or farms in Indiana so that people can have information on whether or not it is profitable to adopt solar PV systems.

Much of the attention has been on the economics of adopting solar PV systems in residential areas. However, farm businesses offer an important opportunity as energy costs represents up to 6% of total farm expenses on average costing farmers $10 billion in annual energy bills (Brown and Elliot, 2005). Also, solar equipment can be depreciated for tax purposes if it is installed in a business.

Therefore, in this analysis, we examine the economics of solar PV systems in Indiana in both residential areas and farm businesses and, since there is a difference in policies currently implemented between these two sectors, we also compare these two sectors from an economic perspective. The specific aims of this study are as follows:

1) Calculate annualized cost of solar PV system in residential areas and farm businesses in Indiana
2) Conduct stochastic analysis for key uncertain variables
3) Calculate the probability that solar PV systems can be less expensive than grid electricity in residential areas and farm businesses
4) Do scenario analysis on different combinations of policy options based in residential areas and farm businesses
5) Perform sensitivity analysis

Through calculating the annualized cost of installing solar PV systems in Indiana under current incentive policies in residential and farm businesses, customers of electricity can be informed if it is better to adopt solar PV systems than to continue relying solely on electricity from the grid. Since there is uncertainty in some input variables such as grid electricity price projections and solar technology, we do a stochastic analysis to capture the uncertainty. The stochastic analysis makes the annualized solar cost a distribution, not just a single deterministic value so that it is possible to calculate a probability that solar PV systems can be a cheaper pathway than electricity from the grid. We also introduce possible policy options to see how they affect the economics of solar PV systems based on the probability that solar can be cheaper. Finally, we also conduct sensitivity analyses on several important variables to see how changes in the variables may affect the robustness of our results.

2. Methods

2.1. Literature Review

Many papers have examined the economics of installing solar PV systems. Most of the papers present a levelized cost of electricity (LCOE) of the solar PV system. According to Borenstein (2007), in California, the LCOE of solar PV system per kWh was $0.322. Thus, the solar PV system was not economical to install, compared to the residential retail price of electricity of around $0.14/kWh in 2007 in California (Pacific Gas and Electric, PG&E, Southern California Edison, SCE, California Public Utilities Commission). However, the solar LCOE has decreased significantly in California and is around $0.15/kWh in southern and $0.20/kWh in northern areas (Pickrell et al., 2013). This shows that solar PV may be cost effective compared to $0.15/kWh, the residential retail price in 2013 in California (EIA, 2013). Makhyoun (2012) also estimates that the LCOE of solar PV systems in North Carolina is higher than $0.15/kWh in 2012. However, the LCOE of solar PV system is expected to drop to $0.11/kWh by 2020, while residential retail electricity price is expected to increase. Cai et al. (2013) mentioned that retail electricity price is expected to rise in the future since utility companies need to recover higher fixed costs and may face higher costs due to carbon regulations. Meanwhile, LCOE of solar PV is expected to drop further due to the lower costs of different technologies such as thin-film PV module, organic PV module with flexible panel, etc. in the future.

However, while many papers have studied the economics of southwestern or southern areas in the US where most of the electricity from solar energy is generated, little has been done for mid-western areas such as Indiana or Illinois. Indiana is also expanding its electricity production from renewables including solar energy. Therefore, in order to see if it is efficient for customers to adopt solar PV systems and to provide people with information related to economics of solar PV systems in Indiana, it is necessary to analyze its economics in Indiana.

2.2. Definition of Policies

There are many policies to promote adoption of renewable energy technologies. The policies are mainly related to the monetary benefits in installing a solar PV system. Before proceeding with the analysis, we briefly introduce those policies.

Net metering

Net metering is a policy that requires electricity companies to buy any excess electricity from solar owner connected to grid if they generate more than they consume at that instance. In Indiana, Northern Indiana Public Service Company (NIPSCO) still offers fixed rate net metering. NIPSCO fixed rate net metering provides credits equal to the retail rate when consumers generate excess electricity independent of the timing of generation and consumption.

Financing Tax Benefits

Financing tax benefits is related to interest of a home equity loan. If the loan is used to buy, build, or significantly improve homes, it is called a home equity loan (IRS Publication 936, 2012). Since installing solar PV systems in homes can be regarded as a home improvement, customers can take a home equity loan when they purchase the solar system and there will be a tax deduction based on interest paid on a home equity loan for financing solar PV systems. Interest on any business related loan also is deductible for business applications.

Federal Tax Credits

There is a federal incentive for renewable energy installations. The federal tax credit, established by *The Energy Policy Act of 2005*, is applied to renewable energy generation property in residential units and for businesses. Taxpayers can claim a federal tax credit for 30% of the installation cost of renewable technologies including solar photovoltaic (DSIRE, 2012). There was a limit of $2,000, but it was eliminated in 2009 for solar PV systems installed after 2008 under *the American Recovery and Reinvestment Act of 2009*.

Depreciation Tax Benefits

Internal Revenue Service (IRS) defines, in its publication 946 (2012), that depreciation is an annual income tax deduction for people to recover the cost of certain property while they use the property for business or income-producing activity. Because the solar installation in residential areas is not used in a business, residential property including the solar PV system that is the focus of this study cannot be claimed for a tax deduction under current law. On the other hand, if the solar installation on a farm is used for business, the depreciation benefit would be available for farm businesses.

Carbon Tax

Carbon tax is a policy instrument to tackle issues related to CO_2 emissions. An estimate of Social Cost of Carbon (SCC) is imposed on a negative externality in the form of carbon tax. In most cases, if a carbon tax is imposed on firms or industries, they will pass the burden of the carbon tax onto customers, which, in turn, induces consumers to consume less electricity.

EPA estimates the US SCC to be $38/ton in 2015 (EPA, 2013). According to EPA (2013), the SCC is expected to increase over the time because future emissions might produce larger damages as the economic system gets more stressed in response to greater climate change. EPA (2013) provides the annual growth rate for the SCC estimate between 2010 and 2050. The reported annual growth rates are 1.7% for the period from 2010 to 2020, 1.8% from 2020 to 2030, and 1.6% from 2030 to 2040.

In cases which include carbon tax, after calculating carbon tax each year, we add it to the electricity price in that year, and we get the new electricity price inclusive of the carbon tax. We use this new electricity price which is the sum of electricity price from the grid and carbon tax imposed instead of the base electricity price.

2.3. Comparison between residences and farm businesses

In our analysis, farm businesses and residences face different policies. Farm businesses can depreciate their solar investment and claim tax deduction from the depreciation while residences cannot since depreciation is available for properties used for business or income-producing activities. Based on this, policies currently in effect in Indiana are net metering, financing tax benefits, and federal tax credits in residential areas. In farm businesses, depreciation tax benefit is added on top of the three available for residences. Therefore, we are expecting solar PV systems to be more economically attractive for farm businesses because of the ability of farm businesses to depreciate the solar investment.

We also compare these two sectors under different other policy combinations so that we can see how they are different from an economic perspective. If adopting solar PV systems is shown to be cost competitive, it may be helpful for farm businesses to reduce energy expenses.

In summary, we analyze three scenarios:

1) Scenario 1: Comparison under the current policy set
2) Scenario 2: Comparison using a set of policies we define as leveling the playing field
3) Scenario 3: Comparison with no net metering

Detailed combinations of policies for each case are summarized in Table 1. We denote *"X"* for a policy included and *"-"* for a policy excluded. Scenario 1 is the base case under current policies. We define Scenario 2 as giving the solar system the same benefits as grid electricity—thus the level playing field name. In Scenario 3, we remove net metering, which is a very important policy because it permits customers to sell excess electricity back to the grid if more electricity is produced than consumed.

Table 1. Combinations of Policies for Each Case

Case	**Sector**	**NM**	**F**	**FTC**	**D**	**CT**
Current policy	Farm	*X*	*X*	*X*	*X*	-
	Residence	*X*	*X*	*X*	-	-
Level the playing field	Farm	*X*	*X*	-	*X*	*X*
	Residence	*X*	*X*	-	*X*	*X*
Remove net metering	Farm	-	*X*	*X*	*X*	-
	Residence	-	*X*	*X*	-	-

* NM: Net Metering, F: Financing, FTC: Federal Tax Credits, D: Depreciation, CT: Carbon Tax

2.4. Analytic Methods

Benefit-Cost Analysis

Benefit-cost analysis is used to evaluate the economics of solar PV systems under operating conditions in Indiana. A key indicator of economic viability is the comparison between the annualized cost of installing a solar PV system and the expected annualized cost of electricity supplied from the grid per kWh.

The annualized cost of a solar PV system per kWh is the annuity of the net present value (NPV) of total system costs per kWh of electricity from the system, and it can be estimated from the ratio of annualized cost to the household’s annual demand for electricity according to the following reduced equation (1).

$$Annualized\ cost\ of\ solar\ PV\ system\ per\ kWh) = {}^{Annualized\ cost}\!/_{Household's\ annual\ demand\ for\ electricity} \tag{1}$$

The annualized cost in the numerator is calculated by multiplying NPV by the capital recovery factor (CRF) for the interest rate and time period used. It is necessary to calculate the annualized cost for grid electricity because we use Indiana projections for increasing grid electricity through the life of the solar system. NPV for annualized cost represents the NPV inclusive of all costs and benefits involved in installing and operating the solar systems, such as initial investment cost, operation and maintenance (O&M) cost, or repair cost. Specific costs and benefits included in the annualized cost are described below in detail:

1) IIC is initial installation cost. This is the cost of the solar PV system in the beginning of the first year including solar panels, inverters, stands, labor, and installation costs.
2) AC_j is annual cost in year j. The annual cost in year j can be calculated by equation (2):

$$AC_j = EC_j + LP_j + O\&M_j + RC_j - B_j \tag{2}$$

   a) EC_j represents cost of electricity not produced from solar and purchased in year j after solar PV system is installed. Since the solar PV system considered in this study does not always produce more electricity than the consumer needs, consumers still need to buy electricity from the grid.

b) LP_j is annual loan payment from financing in year j.

c) $O\&M_j$ is operation and maintenance cost in year j.

d) RC_j presents cost for repairs if the system has any failure in year j.

e) B_j represents benefits for installing solar PV systems in year j. The possible benefits in this study are federal tax credits, depreciation tax deduction, home equity loan tax deduction, and salvage value.

The expected annualized electricity price from grids per kWh means the NPV of 1kWh of electricity converted to an annuity. Because we consider a 20-year period and the electricity price increases year by year at a 1.34% growth rate (Phillips et al., 2013), we can't use the base electricity price ($0.1064 per kWh in January 2015) for comparison. Rather, we need to calculate the expected annualized electricity cost. Therefore we compare the annualized solar cost with the annualized grid cost to have a direct comparison.

Stochastic Analysis

In order to make our analysis more realistic, we consider uncertainty in several key input variables that may have a great impact on the annualized cost of the solar PV systems. There are three uncertain input variables in our analysis; they are 1) current and expected future residential electricity price from the grid, 2) degradation rate of power generated from solar systems, and 3) failure rate for system panels. We calculate stochastic values of electricity price per kWh of solar system rather than using just deterministic values. The stochastic values provide more complete indication of the annualized solar cost than simply calculating the annualized cost with deterministic input variables (Darling et al., 2011).

The analytical process is called Monte Carlo simulation. We use an add-in to Excel called @Risk to do the analysis. The spreadsheet calculations are done 5,000 times, with each iteration representing a draw from each of the uncertain distributions. The results for each iteration are stored by @Risk so that we end up with output distributions of NPV or whatever variables we choose. The output distributions reflect the inherent uncertainty in all the input distributions.

Uncertainty of Electricity Price from the Grids

To do the stochastic simulation of electricity price, we need to determine what distribution would be appropriate to assume for electricity price change. We conduct the normality test for the change of electricity price based on the historical data from 1960 to 2012 (EIA) using the Shapiro-Wilk test with the null hypothesis of normal distribution. It shows that the electricity price change is normally distributed with a p-value of 0.1929, which is greater than 0.05 which is a chosen alpha level, and we fail to reject the null hypothesis. Therefore, we use the normal distribution for the change of electricity price.

For price projection with uncertainty introduced, we take the price for the first year as the base price and make the price for subsequent years dependent on the lagged price, a trend value, and a random component. We add random component with 0 for mean and 10% of the previous year's price for standard of deviation.

$$EP_k = EP_{k-1} \times (1 + EGR) + RiskNormal(mean, standard\ deviation) \tag{3}$$

1) EP_k is the residential electricity price in year k
2) EP_{k-1} is the residential electricity price in year $k-1$
3) EGR is the growth rate of the residential electricity price

4) $RiskNormal(mean, standard\ deviation)$ is the part for random component with its mean and standard deviation.

Uncertainty in Degradation

Performance of the solar PV system over its lifetime is highly dependent on the assumed degradation rate of the panels. Degradation occurs due to chemical processes such as weathering, oxidation, corrosion, or thermal stress (Realini, 2003; Vazquez and Rey-Stolle, 2008). Due to degradation, electricity produced from the solar PV system decreases gradually year by year. Most studies show that the degradation rate is 0.3% - 3% and expected to rise during its lifetime (19th – 20th year of the system) (Vazquez and Rey-Stolle, 2008; Branker et al., 2011; Jordan and Kurtz, 2013). We use a Pert distribution for the uncertainty in degradation in the future. The Pert distribution is convenient because the inputs for the distribution are the minimum value, the most likely value (mode), and the maximum value. In that sense, it is similar to a triangular distribution but has properties that lead us to choose it over the triangular. Table 2 provides the min, mode, and max values for the degradation rate we obtained from the literature and also the calculated average (mean) value. Years 19 and 20 have higher degradation rates than earlier years. We assume no correlation across years, so the system capacity each year is determined by the capacity from the previous year and the stochastic draw from the degradation rate distribution.

Table 2. Values of the Degradation Rate for the Pert Distributions

Variable Name	Distribution	Period	Min (%)	Mode (%)	Max (%)	Mean (%)
Degradation Rate	Pert	1-18	0.3	0.5	1	0.550
		19-20	0.3	0.75	3	1.050

(Source: Vazquez and Rey-Stolle, 2008, Jordan and Kurtz, 2013)

Uncertainty in Failure Rate

We also consider failure rate of the solar PV system panels. The failure rate represents the rate of physical failure of the system panels; for example, defects caused by extreme weather such as hail, thunderstorm, or rocks. The solar PV system usually consists of multiple arrays which are independent of each other. In other words, even if a single array is broken, other arrays are still working. Hence, all we need to do is to replace the single broken array.

Because there is no real experiment for failure rate over 20 years, we assume the average failure rate of the system is 0.5% a year for each single array, and it remains the same over 20 years as suggested by New Holland Rochester, Inc. (NHR, Inc.), the local retailer of the solar PV system in Rochester, IN.

For calculating how many arrays fail annually with 0.5% failure rate, we introduce the Bernoulli trials since the outcome of each array is classified in but one of two mutually exclusive ways, non-defective or defective, and the possibility of each array's failing is independent (Hogg et al., 2012). Thus, we let $X,$ a random variable associated with the Bernoulli trial, be defined as follows.

$$X(non-defective) = 0$$

$$X(defective) = 1$$

In addition, we also define that p is the probability of failure for each array and n is the number of arrays, 24 arrays and 32 arrays in this study. Hence, we assume that the failure rate follows

Binomial distribution with its failure rate (p) of 0.5%, and the number of trials (n) of 24 and 32 arrays, which is $binomial(n, p)$.

The expected value for the number of failure can be calculated by multiplying n and p since the failure rate follows the binomial distribution. We assume that there is no correlation from year to year, so a separate Risk Binomial variable is included for each year. Then, if we multiply the replacement cost of a single array of the system by the stochastic draw from the binomial distribution, the cost for broken array can be estimated.

In addition to the cost of array, customers need to pay labor cost for replacing a broken array. We assume that the labor cost is $75 including driving to and back from the location and repairing, and its annual growth rate in nominal terms is 1% based on NHR, Inc and converted into real value for this analysis.

The arrays often come with a warranty. In this case, the warranty covers all the replacement cost in years 1-10, and 50% of the cost after the 10th year. Values of the failure rate for binomial distribution are summarized in Table 3.

Table 3. Values of the Failure Rate for Binomial Distribution for the 5.88kW and the 7.84kW System Capacities

Variable Name	Capacity	Distribution	Number of panels (n)	Failure Rate (p)	The Expected Value
Failure Rate	5.88kW	Binomial	24	0.5%	0.12
	7.84kW		32		0.16

2.5. Data and Assumptions

The assumptions of the benefit-cost analysis are listed in Table 4. In this study, we mostly use information for the solar PV system based on New Holland Rochester, Inc. because it is a local retailer of solar PV panels in Indiana. This way, our analysis can be more relevant for customers in Indiana. New Holland Rochester, Inc. provides two capacities of solar PV systems, 5.88kW and 7.84kW. The annual electricity generated from solar PV systems also comes from experiments conducted by New Holland Rochester, Inc.

Table 4. Benefit Cost Analysis Assumptions

Assumption for Analysis of Solar PV System in Indiana			
Parameter	**Value**	**Units**	**Source**
PV Panel Capacity (smaller size)	5.880	kW	New Holland Rochester, Inc.
PV Panel Capacity (larger size)	7.840	kW	New Holland Rochester, Inc.
Installation Cost of PV Panel	2.857	$/W	New Holland Rochester, Inc.
Initial Annual Electricity Generated by PV Panel (5.88kW)	9,018.20	kWh/year	New Holland Rochester, Inc.
Initial Annual Electricity Generated by PV Panel (7.84kW)	12,024.27	kWh/year	New Holland Rochester, Inc.
O&M Cost	0.005	$/kWh	New Holland Rochester, Inc.
O&M Cost Growth Rate (Nominal)	3	%	New Holland Rochester, Inc.
O&M Cost Growth Rate (Real)	0.49	%	Author's Calculation
Wire Cost	6.00	%	New Holland Rochester, Inc.
Failure Rate of Panel	0.5	%	New Holland Rochester, Inc.
Labor Cost of Repair	75	$	New Holland Rochester, Inc.
Growth Rate of Labor Cost (Nominal)	1	%	New Holland Rochester, Inc.
Degradation Rate of Electricity Generated from PV system (Mode, 1st through 18th year)	0.55	%	Vazquez and Rey-Stolle, 2008, Jordan and Kurtz, 2013
Degradation Rate of Electricity Generated from PV system (Mode, 19th through 20th year)	1.05	%	Vazquez and Rey-Stolle, 2008, Jordan and Kurtz, 2013
Solar PV Panel Life	20	years	New Holland Rochester, Inc.
Inflation Rate	2.50	%	Author's assumption
Current Retail Electricity Price	0.1064	$/kWh	EIA, Jaunary 2015
Annualized Electricity Price	0.1152	$/kWh	Author's calculation
Current Electricity Price Growth Rate (Real)	1.34	%	Phillips et al., 2013
Discount Rate (Real)	6.00	%	Author's assumption
EPAct 2005 Federal Tax Credit	30.00	%	DSIRE
Loan fraction of total cost	80.00	%	Author's assumption
Loan Interest Rate (Nominal)	7.50	%	Average estimation around Lafayette, IN
Loan Financing Period	10	years	Author's assumption
Salvage Value Rate	15.00	%	Author's assumption
Annual Demand for Electricity	12,428.17	kWh/year	EIA

3. Results and Discussions

3.1. Annualized Electricity Price

We have two annualized electricity prices for comparison:

- Annualized electricity price for cases that do not include a carbon tax
- Annualized electricity price for cases that include a carbon tax.

The annualized real grid electricity prices for both cases are shown in Table 5. The case with carbon tax is, of course, higher. This annualized grid electricity price distribution is compared with the distribution of annualized solar costs in each of the cases to be presented below. Then, we get the distribution of the difference between the two by subtracting the distribution of the annualized electricity price from the distribution of the annualized solar costs to determine the probability that the cost of solar systems will be less than the annualized electricity price.

Table 5. Annualized Grid Electricity Price without and with Carbon Tax

	Mean $/kWh	**Standard Deviation $/kWh**
Annualized Electricity Price without Carbon Tax	0.1152	0.0249
Annualized Electricity Price with Carbon Tax	0.1393	0.0240

3.2. Scenario analysis

Scenario 1: Current Policy

Under the set of policies that constitute the current policy (net metering, financing, and federal tax credit for the homeowner plus depreciation for the business), the solar PV system is economical for farm businesses in Indiana with an 88% probability of being cheaper than electricity from the grid. This very positive outcome is attributed primarily to the tax deduction from depreciation available for farm businesses. On the other hand, for residential customers, the solar system shows 40% of chance of being less expensive than grid, which is a little below breakeven under current policy.

Scenario 2: Comparison Using a Set of Policies We Define as Leveling the Playing Field

We define “leveling the playing field” as giving solar the same benefits accorded to grid electricity to both farm business and homeowners. Thus both would have net metering, financing, and depreciation—the benefits available to grid providers, but not the federal tax credit (unavailable for fossil based electricity). In addition, the carbon tax would be included because it would be necessary to make grid electricity equivalent to carbon free solar. In this case, residential and farm solar both have a 78% of chance of being less expensive than grid. Because residential and farm businesses get benefits from depreciation and carbon tax, it shows a higher probability of being cheaper than under the current policy case.

Scenario 3: Current Policy Without Net Metering

Removing net metering from the current policy makes residential solar uneconomical. On the other hand, farm solar is still attractive even if not so much as with net metering in place with a probability of being less expensive than the grid of 68-83 percent. Clearly, net metering plays an important role in reducing the cost of solar PV systems. Also, we can see that the larger system without net metering is less attractive than the smaller one, even though the larger one generates more electricity. Without net metering, excess electricity would be discarded instead of being sold to the utility. Thus, the larger system shows lower economic viability. The net metering case is important because not all utilities offer net metering or offer net metering under different terms than those considered here.

Table 6. Results for Case Analyses

Case	**Sector**	**Policy Options Included**	**System Capacity kW**	**Solar System Annualized Cost $/kWh**		**Probability Solar Cheaper %**
Under current policy	Farm	NM, F, FTC, D	5.88	Mean	0.0967	88.1
				Standard Deviation	0.0081	
			7.84	Mean	0.0902	88.1
				Standard Deviation	0.0024	
	Residential	NM, F, FTC	5.88	Mean	0.1174	40.1
				Standard Deviation	0.0079	
			7.84	Mean	0.1178	41.1
				Standard Deviation	0.0024	
Level the playing field	Farm	NM, F, D, CT	5.88	Mean	0.1261	77.8
				Standard Deviation	0.0080	
			7.84	Mean	0.1215	78.0
				Standard Deviation	0.0024	
	Residential	NM, F, D, CT	5.88	Mean	0.1261	77.8
				Standard Deviation	0.0080	
			7.84	Mean	0.1215	78.0
				Standard Deviation	0.0024	
Remove net metering	Farm	F, FTC, D	5.88	Mean	0.1001	83.0
				Standard Deviation	0.0085	
			7.84	Mean	0.1048	68.4
				Standard Deviation	0.0054	
	Residential	F, FTC	5.88	Mean	0.1208	31.9
				Standard Deviation	0.0090	
			7.84	Mean	0.1324	17.7
				Standard Deviation	0.0054	

* Mean annualized electricity prices are $0.1152 without CT and $0.1393 with CT

3.3. Sensitivity Analysis

Here we do the sensitivity analysis on panel lifetime and discount rate, two of the most important variables. We have assumed, because New Holland Rochester, Inc. offers a 20-year warranty and panel lifetime for our analysis. However, many panels currently come with a longer period of warranty. Thus, we do the sensitivity analysis over a 25-year and 30-year lifetime. Since most of the 20-year cost of installing a solar PV system is incurred at the beginning of year 1, we do sensitivity on the real discount rate using values of 3%, 4.5%, 7.5%, 9%, and 10.5% in addition to the 6% of the base case. We also did sensitivity analysis for annual operating and maintenance cost, but it is not reported here because there was little impact.

First, we represent how much the probability solar is cheaper will change if we apply longer lifetime periods of 25 and 30 years. As shown in Table 7, the probability increases substantially with longer panel lifetime. This indicates that solar electricity can be more attractive if experience confirms the longer lifetime is appropriate.

Second, Table 8 illustrates the result for the sensitivity analysis for the discount rate. Mostly, the probability solar is less expensive decreases with an increase in discount rate and vice versa. This change is due to the high capital intensity of solar systems. For solar, most of the 20-year cost is incurred at the beginning of year 1, so a high discount rate that reduces the value of future savings will make solar less attractive, while a lower discount rate that values future benefits more will make solar more attractive.

Table 7. Sensitivity Analysis for the Lifetime of PV panels

Case	Sector	Policy Included	System Capacity	Probability Solar Less Expensive (%)		
				Base	**25 years**	**30 years**
Under current policy	Farm	NM, F, FTC, D	5.88kW	88.1	93.5	95.0
			7.84kW	88.1	92.6	94.9
	Residential	NM, F, FTC	5.88kW	40.1	57.7	66.3
			7.84kW	41.1	54.4	63.6
Level the playing field	Farm	NM, F, D, CT	5.88kW	77.8	88.3	91.4
			7.84kW	78.0	85.0	87.8
	Residential	NM, F, D, CT	5.88kW	77.8	88.3	91.4
			7.84kW	78.0	85.0	87.8
Remove net metering	Farm	F, FTC, D	5.88kW	83.0	89.8	93.1
			7.84kW	68.4	79.4	84.8
	Residential	F, FTC	5.88kW	31.9	49.5	60.2
			7.84kW	17.7	31.4	42.2

* Mean annualized electricity prices are $0.1152 without CT and $0.1393 with CT

Table 8. Sensitivity Analysis for the Discount Rate (-50% to +75% of the base assumption)

Case	**Sector**	**System Capacity**	**Probability Solar Less Expensive (%)**					
			-50%	**-25%**	**Base**	**+25%**	**+50%**	**+75%**
Under current policy	Farm	5.88kW	95.0	92.5	88.1	82.3	74.1	65.8
		7.84kW	96.3	92.6	88.1	82.6	74.5	66.6
	Residential	5.88kW	66.9	53.7	40.1	27.5	17.6	10.2
		7.84kW	67.2	54.1	41.1	27.9	17.8	10.6
Level the playing field	Farm	5.88kW	93.0	87.7	77.8	65.8	52.3	39.1
		7.84kW	93.8	87.5	78.0	66.4	53.4	39.3
	Residential	5.88kW	93.0	87.7	77.8	65.8	52.3	39.1
		7.84kW	93.8	87.5	78.0	66.4	53.4	39.3
Remove net metering	Farm	5.88kW	92.8	88.4	83.0	75.8	65.9	55.9
		7.84kW	85.7	77.8	68.4	57.8	45.5	34.3
	Residential	5.88kW	60.2	45.9	31.9	20.7	12.0	6.9
		7.84kW	42.8	28.2	17.7	9.5	4.9	2.0

* Mean annualized electricity prices are $0.1152 without CT and $0.1393 with CT

4. Conclusions

Farm businesses clearly show a higher chance of solar being less expensive than the grid compared to residential customers, except in the level playing field case, in which they are equal. Business solar is more attractive because of the depreciation benefits currently available to farm businesses.

Under current policy, with the benefit of depreciation, the solar system is much more attractive for farm businesses than for residential customers. Farm solar systems have an 88% chance of solar being cheaper than grid electricity, while residential solar shows a 40% chance of being cheaper. For the level playing field case, both residential and farm solar have a 78% chance that solar is less expensive than grid electricity. In this case, residential and farm solar are both economical with an introduction of depreciation and carbon tax. In this case, depreciation levels the playing field, and the carbon tax prices the GHG externality. The policy changes that would level the playing field (depreciation and adding a carbon tax) are more powerful in inducing investment in solar energy than the current federal tax credit, particularly in the residential sector. Removing net metering from the current policy renders residential solar un-economical. Farm solar shows a lower probability of being less expensive than the grid, but it is still attractive.

We also conduct sensitivity analysis for three variables; lifetime of solar PV panels, discount rate, and O&M cost growth rate. The lifetime of panels and the discount rate change the results significantly, while the O&M cost growth rate does not. The longer period of panel lifetime is important in reducing cost. A higher discount rate makes solar less attractive because solar systems are so capital intensive with the costs being up front and the benefits downstream.

Furthermore, this research also suggests the importance of non-profit rural electric cooperatives partnering with for-profit rural businesses in order to increase use of solar energy. Non-profits cannot take advantage of the tax deductibility of loans, the federal tax credit, or depreciation because they do not pay federal income taxes. Without these provisions, solar clearly is not economical. However, if rural electric cooperatives find creative ways to partner with for-profit rural businesses, then greater solar penetration can be achieved in a way that is beneficial for both entities—a win-win.

References

Borenstein, S., 2007. Electricity Rate Structures and the Economics of Solar PV: Could Mandatory Time-of-Use Rates Undermine California's Solar Photovoltaic Subsidies? Center for the Study of Energy Markets, University of California Energy Institute, UC Berkeley.

Branker, K., Pathak, M.J.M., Pearce, J.M., 2011. A Review of Solar Photovoltaic Levelized Cost of Electricity. Renewable and Sustainable Energy Reviews. 15, 4470-4482.

Brown, E. and Elliott, N., 2005. On-Farm Energy Use Characterizations. Report Number IE052. American Council for an Energy-Efficient Economy (ACEEE).

Cai, D.W.H., Adlakha, S., Low, S.H., Martini, P., Chandy, K.M., 2013. Impact of Residential PV Adoption on Retail Electricity Rates. Energy Policy. 62, 830-843.

California Public Utilities Commission. Rate Charts and Tables – Electricity. Available at http://www.cpuc.ca.gov/PUC/energy/Electric+Rates/ENGRD/ratesNCharts_elect.htm.

Darling, S.B., You, F., Veselka, T., Velosa, A., 2011. Assumptions and the Levelized Cost of Energy for Photovoltaics. Energy Environ. Sci. 4, 3133-3139.

Hogg, R.V., McKean, J.W., Craig, A.T., 2012. Introduction to Mathematical Statistics, seventh edition. Pearson.

Internal Revenue Service (IRS)., 2012. How to Depreciate Property, Publication 946.

Internal Revenue Service (IRS)., 2012. Home Mortgage Interest Deduction, Publication 936.

Jordan, D.C., Kurtz, S.R., 2013. Photovoltaic Degradation Rates-An Analytical Review. Prog. Photovolt: Res. Appl. 21, 12-29.

Makyoun, M., Crowley, R., Quinlan, P., 2012. Levelized Cost of Solar Photovoltaics in North Carolina. NC Sustainable Energy Association.

New Holland Rochester, Inc. Available at http://www.newhollandrochester.com/solar.php.

Phillips, P., Velastegui, M.,Gotham, D., Nderitu, D., Preckel, P., Phillips, T., Mize, D., 2013. Indiana Electricity Projections, The 2013 Forecast. State Utility Forecasting Group, The Energy Center at Discovery Park, Purdue University.

Pickrell, K., DeBenedictis, A., Mahone, A., Price, S., 2013. Cost-Effectiveness of Rooftop Photovoltaic Systems for Consideration in California's Building Energy Efficiency Standards. California Energy Commission. Publication Number: CEC-400-2013-005-D.

Realini, A., 2003. Mean Time Before Failure of Photovoltaic Modules. Final Report (MTBF Project), Federal Office for Education and Science Tech. Rep., BBW. 99.

U.S. Energy Information Administration., 2013. Electric Sales, Revenue, and Average Price.

U.S. Energy Information Administration., 2015. Average Retail Price of Electricity to Ultimate Customers by End-Use Sector.

U.S. EPA., 2013. Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866.

U.S. EPA., 2013. Fact Sheet: Social Cost of Carbon.

Vazquez, M., Rey-Stolle, I., 2008. Photovoltaic Module Reliability Model Based on Field Degradation Studies. Prog. Photovolt: Res. Appl. 16, 419-433.