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A Consequential Life Cycle Assessment of the SCEIP Financing Program for Residential Photovoltaics in Sonoma County, CA: determining the life cycle carbon and energy cost benefit

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SSEBE-CESEM-2012-CPR-008
Course Project Report Series

May 2012

ASU Ira A. Fulton Schools of Engineering

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Submitted May 1, 2012

ENERGY INDEPENDENCE
A SONOMA COUNTY PROGRAM

GLOBAL INSTITUTE of SUSTAINABILITY
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Executive Summary

Sonoma County, CA is on an ambitious pathway to meeting stringent carbon emissions goals that are part of California Assembly Bill 32. At the county-level, climate planners are currently evaluating options to assist residents of the county in reducing their carbon footprint and also for saving money. The Sonoma County Energy Independence Program (SCEIP) is one such county-level measure that is currently underway. SCEIP is a revolving loan fund that eligible residents may utilize to install distributed solar energy on their property. The fund operates like a property tax assessment, except that it only remains for a period of 20 years rather than in perpetuity.

This analysis intends to estimate the potential countywide effect that the $100M SCEIP fund might achieve on the C02 and cost footprint for the residential building energy sector. A functional unit of one typical home in the county is selected for a 25 year analysis period. Outside source data for the lifecycle emissions generated by the production, installation and operations of a PV system are utilized. Recent home energy survey data for the region is also utilized to predict a "typical" system size and profile that might be funded by the SCEIP program. A marginal cost-benefit calculation is employed to determine what size solar system a typical resident might purchase, which drives the life cycle assessment of the functional unit. Next, the total number of homes that might be financed by the SCEIP bond is determined in order to forecast the potential totalized effect on the County's lifecycle emissions and cost profile.

The final results are evaluated and it is determined that the analysis is likely conservative in its estimation of the effects of the SCEIP program. This is due to the fact that currently offered subsidies are not utilized in the marginal benefit calculation for the solar system but do exist, the efficiency of solar technology is increasing, and the cost of a system over its lifecycle is currently decreasing. The final results show that financing distributed solar energy systems using Sonoma County money is a viable option for helping to meet state mandated goals and should be further pursued. The final results for the SCEIP versus No-SCEIP scenarios are shown in the below table for both carbon and energy costs.

Lifecycle Cost of Energy (County Level)		Lifecycle Carbon Emissions - Tons (County Level)	
SCEIP	No SCEIP	SCEIP	No SCEIP
$374,061,487.31	$723,381,404.72	463514.3	577690.8

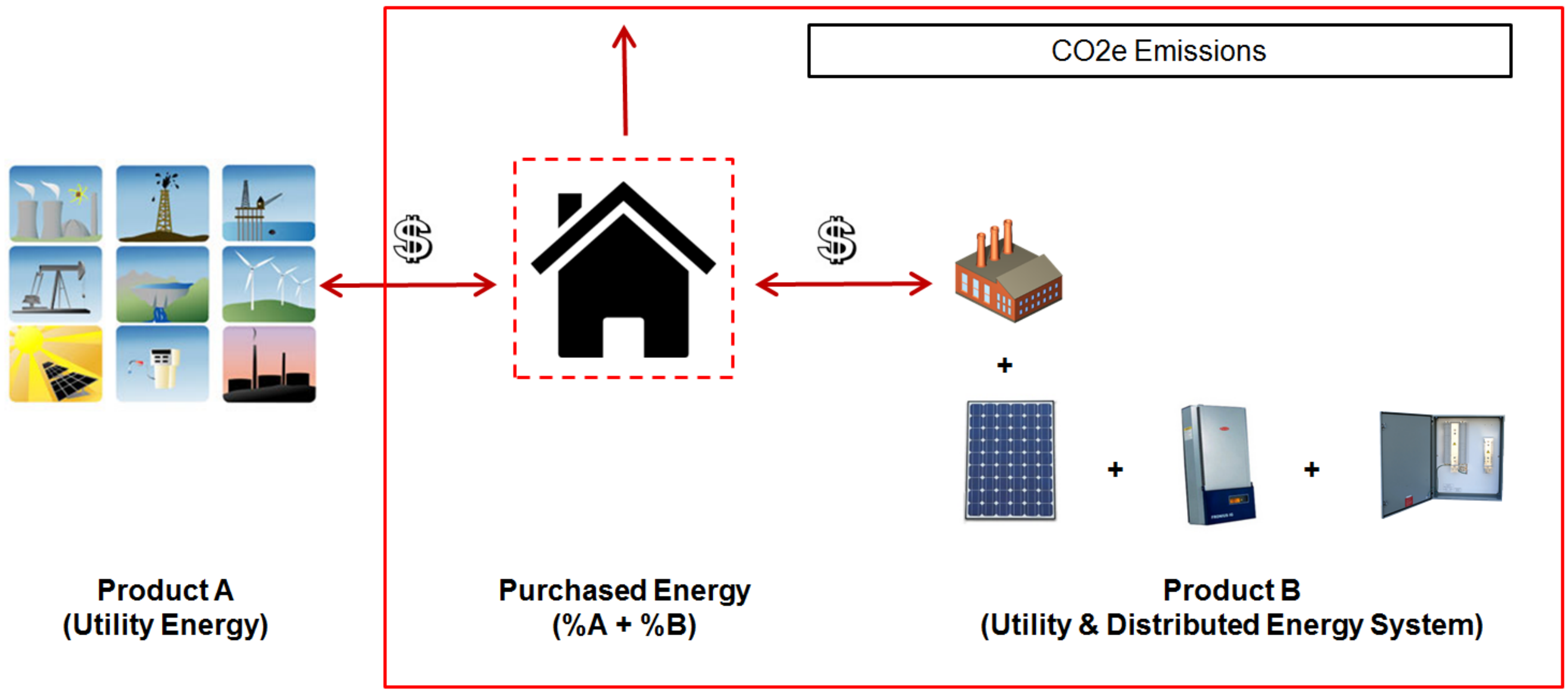
Background

In 2006 the State of California passed Assembly Bill 32 "The Global Warming Solutions Act", which aims to reduce statewide emissions of greenhouse gases to 1990 levels by 2020, a net reduction of 25% over current levels. To achieve this goal, the state tasked the California Air Resource Board (CARB) with developing an emissions-reduction scoping document (from 2007-2011) and implementing the measures corresponding to this document beginning January 1, 2012. As part of this implementation procedure CARB has encouraged partnerships with various local governments to voluntarily take-part in the emissions reductions effort. Currently, the most aggressive local government effort to reduce regional emissions is occurring in Sonoma County, CA – which is situated in the North Bay Area. In order to meet the objectives of AB32, Sonoma County is currently weighing various technology options for intervening in the local electricity mix to reduce GHG emissions. As part of the intervention, Sonoma County has launched an ambitious financing program – known as the Sonoma County Energy Independence Program (SCEIP) – to promote distributed electricity generation via solar photovoltaic (PV) installations at the distributed residential building level. This generation in intended to replace the electricity purchased from and thus generated by the utility (PG&E), and during the operational phase is GHG neutral.

Scope

The purpose of this analysis is to evaluate what the consequential impact of providing $100M of SCEIP financing to the typical Sonoma County residence would be across the entire population of program stakeholders (e.g. participating homeowners). In order to perform the analysis, a functional unit of the amount of energy required to power a typical home for 25 years was chosen for evaluation, with the evaluation being performed at a scale equal to the number of homes that could reasonably be expected to receive financing until the entire bond was exhausted. Additionally, it is assumed that the provision of the SCEIP bond and the residential solar systems that are installed as a result of its availability do not actively change the footprint associated with the production of utility energy. This is because the net amount of total retail energy demanded from the utility changes very minutely. Therefore, the system boundary for Product A (Utility Energy) does not account for upstream changes to mining, extraction or transportation of fuels to the utility. However, it is assumed that demand for Product B (Utility + Distributed Energy System) marginally adds to the world demand for PV equipment, and therefore the impacts of all new upstream manufacturing, transportation and construction activities associated with the solar system – such as the purification of silicon and installation of inverters – is allocated to the newly demanded solar equipment. A system boundary diagram is illustrated below.

System Boundary Diagram



Reference Model and Life Cycle Inventory

The scope of the analysis and selected system boundary parameters requires various inputs in order to calculate the life cycle primary energy consumption associated with the manufacturing and installation of the Distributed Energy System components. Fortunately, a full evaluation of this was performed using modern and comparable technology configurations for a test PV system installed in Ann Arbor, MI (Pacca, Sivaraman, and Keoleian 3316-3326)[1]. This evaluation uses a reference system that is comprised of c-Si solar modules, inverters, and all required balance-of-system parts to estimate the primary energy required throughout the systems lifecycle phases of component manufacturing, transportation to site, installation and operations. Using SimaPro 6.0, the authors developed the following process-based inventory and results.

Distributed Energy System Primary Energy LCI				
No	Materials	Mass (g / Wp)	Primary Energy (MJ / Wp)	LCI Source*
1	Argon	4.800	0.010	ETH / Alsema
2	Hydro fluoric acid	0.900	0.019	ETH / Alsema
3	Sodium hydroxide	4.400	0.042	ETH / Alsema
4	Sulfuric acid	3.300	0.004	BUWAL / Alsema
5	HDPE	8.700	0.642	BUWAL / Alsema
6	Glass	62.400	0.867	BUWAL / Alsema
7	Aluminum	0.001	0.000	BUWAL / Alsema
8	Tin	0.180	0.041	IDEMAT / Alsema
9	Copper	0.180	0.012	ETH / Alsema
10	Polyester	8.800	0.021	IDEMAT / Alsema
11	Ammonia	0.065	0.001	BUWAL / Alsema
12	Nitrogen	0.700	0.002	ETH / Alsema
13	Charcoal	5.200	0.010	ETH / Alsema
14	Coal	7.800	0.239	ETH / Alsema
15	Coke	5.200	0.257	ETH / Alsema
16	Wood	18.300	0.001	ETH / Alsema
17	Silicium carbide	9.600	0.714	IDEMAT / Alsema
18	Tedlar	41.800	0.777	Franklin / Alsema
19	Aluminum	19.600	2.624	BUWAL / Alsema
20	Silicon	37.100	3.137	IDEMAT / Alsema
21	Aluminum	0.400	0.052	BUWAL / Alsema
22	Process energy		25.160	Franklin / Alsema
Total			**34.630**	

These primary energy results were then multiplied through the US average fuel mix database in SimaPro to derive a figure of **72gC02e / kWh** of solar energy produced by the reference system during its lifetime.

[1] Pacca, Sergio, Deepak Sivaraman, and Gregory Keoleian. "Parameters affecting the life cycle performance of PV technologies and systems." *Energy Policy*. 35 (2007): 3316-3326. Print.

Methodology and Other Data / Generated Data

To begin the analysis it is required to estimate the total number of homes that could likely participate in the SCEIP financing program, the average system size and cost per home, as well as the average life cycle cost savings generated per home solar system. This requires a home-level cost-benefit analysis for a "typical" home in Sonoma County to determine how much energy a distributed solar system would need to produce to be marginally beneficial to the customer.

Step 1 - Survey data on home energy consumption levels were gathered and utilized from a recent Lawrence Berkeley National Labs study (Lai et. Al, 2011[2]). In Sonoma County utility customers are charged varying marginal prices for electricity that increase across a 5 tier electricity rate schedule, which in turn depends on how much net energy is consumed above an allotted baseline. Baselines vary by geography, and in Sonoma County 61% of residents fall into the Coastal baseline category and 39% into the Hills & Mountains category. This data was processed by taking a weighted average of the current marginal cost ($ / kWh) paid by residents across both utility territories in Sonoma County. These blended rates were then adjusted again to reflect a population-weighted average marginal cost of electricity experienced by the "typical" Sonoma County home. This was determined to be **$.183 / kWh**, which serves as the assumed hurdle rate required by the solar system (see below Table 1).

	Normalized Customer Usage Data by Territory											Calculated Customer Marginal Cost / kWh	
		Tier 1		Tier 2		Tier 3		Tier 4		Tier 5		Weighted Average Customer	
	Year	Tariff $ / kWh	Usage Annual kWh	Tariff $ / kWh	Usage Annual kWh	Tariff $ / kWh	Usage Annual kWh	Tariff $ / kWh	Usage Annual kWh	Tariff $ / kWh	Usage Annual kWh	Blended Tariff $ / kWh	Total Usage Annual kWh
61% Coastal (Q, T, V)	2006	$ 0.114	2,680	$ 0.130	488	$ 0.230	687	$ 0.322	390	$ 0.371	312	$ 0.169	4,557
	2007	$ 0.114	2,655	$ 0.130	486	$ 0.226	687	$ 0.315	391	$ 0.362	331	$ 0.168	4,550
	2008	$ 0.116	2,653	$ 0.131	480	$ 0.247	674	$ 0.354	378	$ 0.411	333	$ 0.179	4,518
	2009	$ 0.115	2,672	$ 0.131	484	$ 0.261	678	$ 0.381	376	$ 0.443	340	**$ 0.185**	4,550
39% Hills / Mountain (X, Y, Z)	2006	$ 0.114	3,793	$ 0.130	707	$ 0.230	986	$ 0.322	565	$ 0.371	427	$ 0.168	6,478
	2007	$ 0.114	3,760	$ 0.130	700	$ 0.226	969	$ 0.315	540	$ 0.362	393	$ 0.165	6,362
	2008	$ 0.116	3,782	$ 0.131	705	$ 0.247	976	$ 0.354	544	$ 0.411	396	$ 0.176	6,403
	2009	$ 0.115	3,814	$ 0.131	712	$ 0.261	979	$ 0.381	531	$ 0.443	372	**$ 0.180**	6,408

Table 1

[2] Lai, Judy, Nicholas DeForest, Sila Kiliccote, Michael Stadler, Chris Marnay, and John Donadee. Evaluation of evolving residential electricity tariffs.2011. Print.

Step 2 – An evaluation of the average marginal cost of producing solar electricity was performed by taking installation records for existing Sonoma County residential solar systems, available through the California Solar Initiative (CSI) database, to determine the average installation cost per watt peak of nameplate generating capacity. Cost data from the CSI was trimmed to reflect only residential installations that ranged in size from 1-30KW and that were installed in the county in CY2012. The average weighted cost for this set of systems was determined to be \$5.79 / Watt_{DC}.

Step 3 – A solar productivity factor for the region was estimated using NREL's Solar Advisory Model (SAM) to determine production in kWh / KW of system size. As before, the system parameters were set in the SAM model to mirror those of the reference system discussed in *Pacca et.* Al. Then, production was added until the *nth* unit of solar energy generated had less value than the current marginal cost of energy for the typical home. In Sonoma County, this occurred at the 1585th kWh produced by solar. Using the production factor determined by SAM, the typical system size that would be financed by the SCEIP program was estimated to be **1.1KW$_{DC}$.** At the pre-determined \$5.79 / $\text{Watt}_{DC,}$ this implies a total system cost of \$6,369.00 to the customer that would be financed by the SCEIP bond.

Step 4 – A scenario assessment was developed to compare Product A (100% Utility Energy) and Product B (Utility Energy + DG) options. A cost model was developed to determine lifecycle cost implications for scenario "SCEIP" and "No SCEIP", with the stakeholder pro-forma being modeled as a 25 year commitment to purchase the full amount of "typical home" energy required from either Product A or Product B. For the Product B scenario, a 7% simple interest loan corresponding to the cost of the solar energy system was amortized over the 20 year SCEIP loan period to reflect the cost of the voluntary assessment levied to the homeowner by the bond. Solar energy generated was set to degrade at .005% compounding per year to account for the warranted rate of module degradation, which has the effect of requiring additional energy to be purchased from the utility over time. Also, the cost for utility energy was escalated at 5% per year compounding in both scenarios to match historical trends in energy cost escalation. An annual carbon emissions factor was used to determine CO2 emissions from utility-purchased electricity. Finally, a total lifecycle energy mix was developed.

Results

The results of both scenarios may be viewed below for the functional unit of a "typical home" that consumes the average amount of power purchased to operate the home in Sonoma County for a period of 25 years.

Scenario 1 - Provide SCEIP Financing

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25
Solar Energy Produced (kWh)	1585	1577	1569	1561	1554	1546	1538	1530	1523	1515	1508	1500	1492	1485	1478	1470	1463	1456	1448	1441	1434	1427	1420	1412	1405
PG&E Energy Produced (kWh)	3690	3698	3706	3714	3721	3729	3737	3745	3752	3760	3767	3775	3783	3790	3797	3805	3812	3819	3827	3834	3841	3848	3855	3863	3870
Solar Energy Cost ($ / kWh)	($693)	($581)	($581)	($581)	($581)	($581)	($581)	($581)	($581)	($581)	($581)	($581)	($581)	($581)	($581)	($581)	($581)	($581)	($581)	($581)					
PG&E Energy Cost ($ / kWh)	($675)	($711)	($748)	($787)	($828)	($871)	($916)	($964)	($1,015)	($1,067)	($1,123)	($1,182)	($1,243)	($1,308)	($1,376)	($1,448)	($1,523)	($1,602)	($1,685)	($1,773)	($1,865)	($1,962)	($2,064)	($2,171)	($2,284)
Total Cost of Energy	**($1,368)**	**($1,292)**	**($1,329)**	**($1,368)**	**($1,409)**	**($1,452)**	**($1,497)**	**($1,545)**	**($1,596)**	**($1,648)**	**($1,704)**	**($1,763)**	**($1,824)**	**($1,889)**	**($1,957)**	**($2,029)**	**($2,104)**	**($2,183)**	**($2,266)**	**($2,354)**	**($1,865)**	**($1,962)**	**($2,064)**	**($2,171)**	**($2,284)**
Solar CO2 Produced	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
PG&E CO2 Produced (tons)	1.03	1.03	1.03	1.04	1.04	1.04	1.04	1.04	1.05	1.05	1.05	1.05	1.06	1.06	1.06	1.06	1.06	1.07	1.07	1.07	1.07	1.07	1.08	1.08	1.08
Total CO2 Produced	**1.16**	**1.16**	**1.16**	**1.16**	**1.16**	**1.17**	**1.17**	**1.17**	**1.17**	**1.17**	**1.18**	**1.18**	**1.18**	**1.18**	**1.19**	**1.19**	**1.19**	**1.19**	**1.19**	**1.20**	**1.20**	**1.20**	**1.20**	**1.20**	**1.21**

Scenario 2 - No SCEIP Financing

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25
Solar Energy Produced (kWh)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PG&E Energy Produced (kWh)	5275	5275	5275	5275	5275	5275	5275	5275	5275	5275	5275	5275	5275	5275	5275	5275	5275	5275	5275	5275	5275	5275	5275	5275	5275
Solar Energy Cost ($ / kWh)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PG&E Energy Cost ($ / kWh)	($965)	($1,014)	($1,064)	($1,117)	($1,173)	($1,232)	($1,294)	($1,358)	($1,426)	($1,498)	($1,572)	($1,651)	($1,734)	($1,820)	($1,911)	($2,007)	($2,107)	($2,213)	($2,323)	($2,439)	($2,561)	($2,689)	($2,824)	($2,965)	($3,113)
Total Cost of Energy	**($965)**	**($1,014)**	**($1,064)**	**($1,117)**	**($1,173)**	**($1,232)**	**($1,294)**	**($1,358)**	**($1,426)**	**($1,498)**	**($1,572)**	**($1,651)**	**($1,734)**	**($1,820)**	**($1,911)**	**($2,007)**	**($2,107)**	**($2,213)**	**($2,323)**	**($2,439)**	**($2,561)**	**($2,689)**	**($2,824)**	**($2,965)**	**($3,113)**
Solar CO2 Produced	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00
PG&E CO2 Produced (tons)	1.47	1.47	1.47	1.471725	1.47	1.47	1.47	1.471725	1.47	1.47	1.47	1.471725	1.47	1.47	1.47	1.471725	1.47	1.47	1.47	1.471725	1.47	1.47	1.47	1.471725	1.47
Total CO2 Produced	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**	**1.47**

Lifecycle Cost of Energy (Typical Home)	
SCEIP	No SCEIP
$23,824	$46,072

Lifecycle Carbon Emissions - Tons (Typical Home)	
SCEIP	No SCEIP
26.4	36.8

These numbers for the typical home were extrapolated to represent 15,701 homes, which is the total population that could be financed given a $100M SCEIP bond and the system profile determined by this analysis.

Lifecycle Cost of Energy (County Level)	
SCEIP	No SCEIP
$374,061,487.31	$723,381,404.72

Lifecycle Carbon Emissions - Tons (County Level)	
SCEIP	No SCEIP
463514.3	577690.8

Data Quality Assessment

Several key assumptions were made in developing these numbers, which would likely result in multiple discrepancies between modeled and actual conditions. In determining the system boundaries for the consequential LCA we assume:

1. The decision to purchase solar would be made, and only made, if the unsubsidized marginal value of solar energy provided was less expensive than the weighted average value of utility-supplied energy. **However, there is a dynamic market for solar equipment and utility rebates which have the effect increasing the marginal value of solar depending on the time of installation. This would likely increase the system size demanded, driving a change to the lifecycle energy, emissions and fuel mix scenarios.**
2. PGE energy produced and solar energy produced are linearly dependent. **This is likely not the case, as one residential solar energy installation approaches an infinitesimally small value of the overall energy production mix.**
3. Solar energy only competes with PG&E energy and competition is annual in the long-term. **Dependent on the definition of functional unit (in this case supplied energy), solar systems may compete with other sources of distributed energy such as wind or geothermal. Additionally, it is unlikely that the utility profile does not change over the course of the analysis period, which would affect the results of the analysis.**

As with any consequential LCA, it would be a useful exercise to develop additional scenarios that sensitized key variable of interest to establish operating boundaries for the SCEIP program. Doing this would allow for a range of projections to be made that would encapsulate most likely scenarios during the term.

Discussion and Implications for Decision-Making

In evaluating the potential effects on lifecycle carbon and energy costs that would be mitigated by providing the $100M SCEIP bond, Sonoma County should consider the number of changing variables associated with this analysis and revise the estimates frequently to match current conditions. This analysis did not consider a number of important components that are natural to the growth of the solar industry, including rapid advancements in system-level efficiency as well as decreases in cost. Also, peripheral benefits such as the value of hedging energy cost inflation and stimulating the local contractor economy have not been considered. Also, the start-up cost of creating and administering the bond mechanism that allows Sonoma County to offer the SCEIP option is inherent to the calculations via the interest rate charged to consumers. However, if the bond were to be refunded, this cost would not be reoccurring and would result in improved numbers, an increase system size per consumer (because the hurdle rate is lower), and a greater mix of solar energy produced and carbon mitigated.

The SCEIP program has good potential as a comprehensive approach to changing the local energy mix, and it is suggested that the County continue to pursue this option into the future. Perhaps as important, the County should consider revising the program requirements to manage for the minimization of the life cycle carbon produced during the module manufacturing, installation and operations stages. This could likely be achieved by specifying modules which are produced in renewably-powered factories, factories that are nearby, or equipment that doesn't require as much material to produce an equivalent amount of energy (higher conversion efficiency). This analysis could be achieved by expanding off of the results presented herein, and would likely lead to a better understanding of the full effects of the program.