Canoe Creek State Park Photovoltaic System Design

Nicholas Appling, Yewon Jang, Doug Devitt

Dr. Jeffrey Brownson, EGEE 437

Executive Summary

This report pertains to the potential development of a solar photovoltaic system in Canoe Creek State Park, located in Hollidaysburg, PA. This document contains background on photovoltaic systems, Canoe Creek State Park system design, and financial research and recommendations. In Spring 2018, the Blair County Planning Commission--in conjunction with Pennsylvania DCNR representatives--needed to determine the feasibility of a solar PV system in Canoe Creek State Park (CCSP). Blair County Planning, and DCNR representatives wanted to discover if solar energy could run a sewage treatment plant in CCSP, and determine if the energy consumed by multiple cabins, and a small education center on site could be mitigated. To determine the potential of solar photovoltaics at CCSP, our team used a variety of software to analyze the solar resource at CCSP, and design feasible systems to meet our client's goals. We investigated three separate sites: the cabins at CCSP, the education center at CCSP, and the sewage treatment plant at CCSP. The goal of our clients was to reduce energy consumption at all sites, and ideally run the sewage treatment plant (STP) entirely with solar energy. With the assistance of SAM, SketchUp, and Helioscope softwares, our team determined that our client's goals are achievable, but with significant cost. An effective array of PV panels to net zero the STP would require 288 PV modules, to create 154,000 kWh of electricity at a cost of $209,000. To develop PV systems for the cabins and education center, about 20 modules are required for each structure, at a cost of $6,000 for the education center, and $11,000 for each cabin. These arrays would create 6500 kWh of electricity for the cabins, and 3300 kWh of electricity for the education center. However, despite the high initial investment, the financial indicators--particularly NPV--are positive for each site. The sewage treatment plant has an NPV of $88,000, the cabins have an NPV of $130, and the education center has an NPV of $978. However, the payback period for the cabin and education center arrays is greater than 10 years. Despite the high capital cost, production credits, particularly the solar alternative energy credit, are available to offset costs, and these developments likely qualify for PA clean renewable energy bonds to help pay for the initial cost. Overall, based off of our designs, PV arrays to offset the cabin and education center, and net zero the STP are financially viable options at CCSP, though they do require significant initial investment.

Introduction

The Blair County Planning Commission and DCNR representatives, our clients, asked for the solar systems in Canoe Creek State Park. Canoe Creek is located at Hollidaysburg, PA. The park has 961-acre with 155 acre lake, wetlands, old fields, and mature forest. For our project in Canoe Creek State Park, the client's' goal was to offset the energy consumption at the Education Center and cabins with photovoltaic panels, and ideally net zero the sewage treatment plant in the park, essentially meaning three separate arrays were necessary. Although the client's ideal situation was to completely run the sewage treatment plant with solar power, a sizeable offset in energy consumption was an acceptable design, though not ideal. Furthermore, our clients expressed a desire to demonstrate the capability of solar energy to local citizens, and educate visitors on the operations and principles behind solar energy. In addition to these requirements, our clients wanted the PV arrays to have a minimal impact on the environment of Canoe Creek State Park. The design needed to be visible, but not obtrusive. Oversized arrays that require vegetation management don't fit well into the goals of organizations dedicated to the preservation of nature and natural resources. These restrictions meant that panels should ideally be placed on pre-developed, or cleared, but unused parts of the park (e.g. roofs, empty lots, unused cleared spaces). Using existing space efficiently would fit the stated goals and outward appearance of both PA DCNR and Blair County Planning. Finally, our client's wanted to minimize system costs. They did not specify a budget or payback period, though they did express that public sector budgets are typically small. Our client's did express a need for a sound investment, since public sector spending is scrutinized. As such, any financial metrics should indicate that this investment is sound. A positive NPV and payback period under 10 years would clearly indicate the development is safe from a financial perspective.

Operation of PV Panels

When sunlight hits the photovoltaics cells, the light is absorbed and causes a transition in material from ground state to excited state. Then the “free” charge carriers and negative and positive pair is generated, which is also called “photogeneration”. Using a discriminating transport mechanism, it seperates anode and cathode in the charge, and the carrier leaves the cell as high potential electrons, entering the wire. Then the electrons lost energy due to the characteristic resistance from the Load, and pair with positive charge, returning the charge carrier pair to the ground state. This process is done in one photovoltaic cells, which can make up a module, and multiple modules can make up an array. The photovoltaic cells produce a DC power, which needs to be converted into the AC power, which is what we use in daily basis. The inverter converts DC power that PV arrays produce to the AC power. Then the produced electricity can be stored in batteries for later use or send it to the utility grid, where it can serve other buildings or sell the left over electricity to the utility company.

System Design

A variety of factors limited the potential production in our design, particularly location, and array orientation. Our location is squarely in Central Pennsylvania, roughly at a latitude of 40.47’ North. With a location mid-way up the northern hemisphere, the solar resource varies greatly with the season. April through September, plane of array total irradiance is very favorable and consistent. However, October through March, the low path of the sun limits POA irradiance, and t$herefore potential energy production. Figures 1 and 2 illustrate seasonal solar effects.

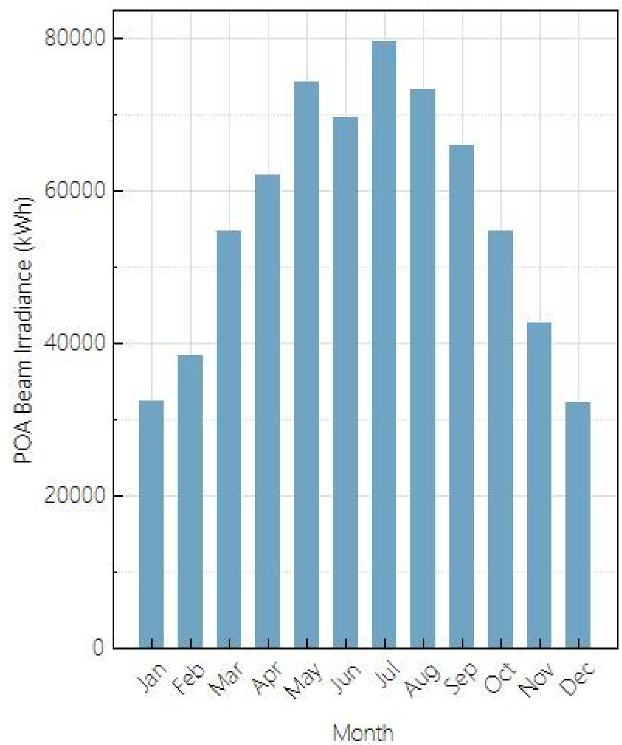


Figure 1: Plane of Array irradiance in terms of kWh

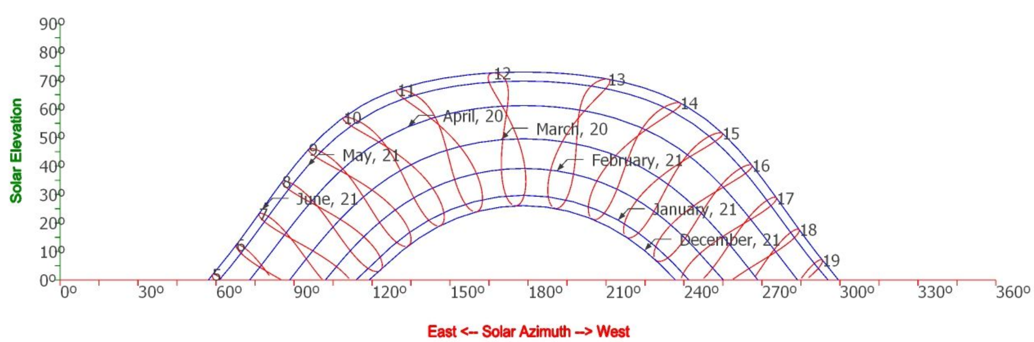


Figure 2: Sun path chart for CCSP site

As Figure 1 clearly illustrates, solar irradiance drops drastically in the time from October to March, with irradiance not breaking 40000 kWh for the majority of those months. Figure 2 shows the sun path for each month. Again, the months from October to March show a marked decline in the sun's travel path and maximum elevation. This shortened path and lowered elevation contribute to the less severe irradiance, but drastically reduce the potential production of any PV array for the time period from October to March. In addition to low irradiance during the winter months, our client's needs limited array orientation for the cabins, and the education center. Our team decided both of these PV arrays should be roof mounted, as this was the least obtrusive design in terms of clearing land or changing the landscape of CCSP. This limited our ability to adjust array tilt, tracking, and orientation for the cabins and education center. One side of each cabin’s roof faces roughly Southeast, with azimuth angles between 120 and 155 degrees. Figure 3 illustrates the roof orientation for the cabins.

Figure 3: Scattered roof orientation for CCSP cabins, limited azimuth angle adjustments

The most southern facing side of the education center has an azimuth angle of 130 degrees. None of these is ideal for PV systems, where northern hemisphere arrays are most productive when they face due South, or an azimuth angle of 180. Furthermore, the arrays for the cabins and education center were small, only 18 modules for the education center, and 20 modules for each of the cabins. The size limited the practicality of tracking systems, and azimuth angle adjustments. Changing the azimuth would severely limit the number of panels able to be placed on each roof, and adding tracking systems would simultaneously increase cost, and increase shading. With no option being ideal, our team chose to simplify the rooftop systems by using only the most southern facing side, and choosing a flush mount system that locked array tilt to the tilt of each roof, roughly 15-20 degrees. Again, these technological challenges limited the potential output of the education center and cabin arrays, since the systems were required to be non-ideal due to client needs. This in turn reduced the financial viability of each investment, but through panel and inverter selection, the NPV was positive, and the payback period was minimized.

On the sewage treatment plant array, a fixed tilt system was not necessary. The size of the array is not as limited as the cabin and education center arrays, and orientation could be adjusted for ideal power output. Due to the variety of design options, and the client need to maximize PV production for the STP, our team decided that 1-axis tracking and true south orientation were effective designs for the STP array. An azimuth angle of 180 degrees does increase array size, and require foliage clearing, but it also maximizes array production. As such, higher power panels were chosen to minimize ground coverage while maximizing power output. 1-axis tracking also has a pronounced effect on energy production. Based off of SAM simulations, cost is unchanged when 1-axis tracking is added, but production increases from

124,000 kWh a year to 154,000 kWh a year for the same array setup. This is a 25% production increase for essentially no additional cost.

For each of the three design locations (Education Center, Cabins, and Sewage Treatment Plant), average monthly data was available, but specific monthly demand was unavailable. However, for the cabins and education center, varying monthly demand was simulated while ensuring the monthly average demand was equal to the data available from our clients. At the sewage treatment plant, demand is far less variable, so average monthly demand was used for the demand in each month, rather than a demand simulation. Figures 4-6 illustrate the monthly load of each location before the recommended PV system.

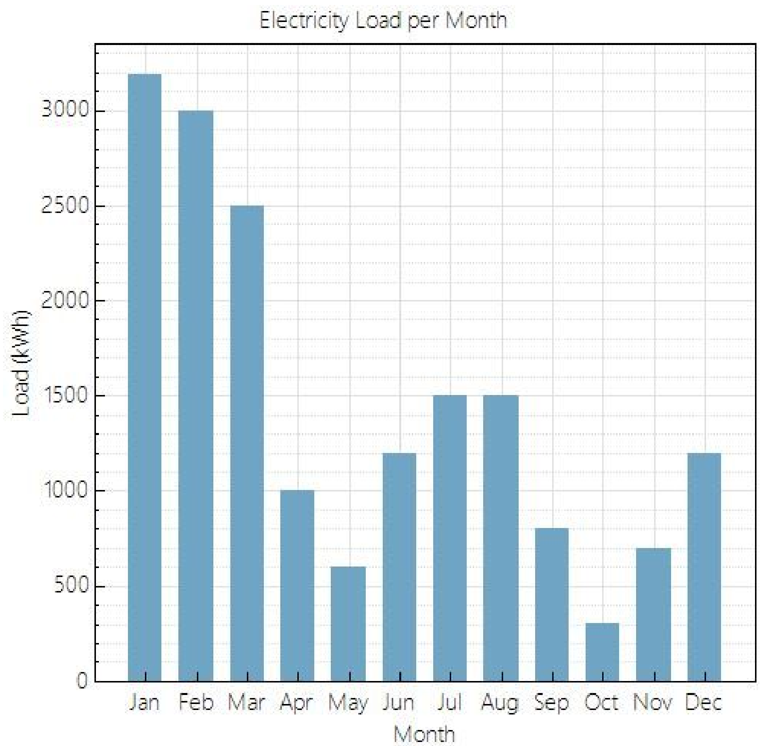


Figure 4: Cabins electricity load per month w/o PV system

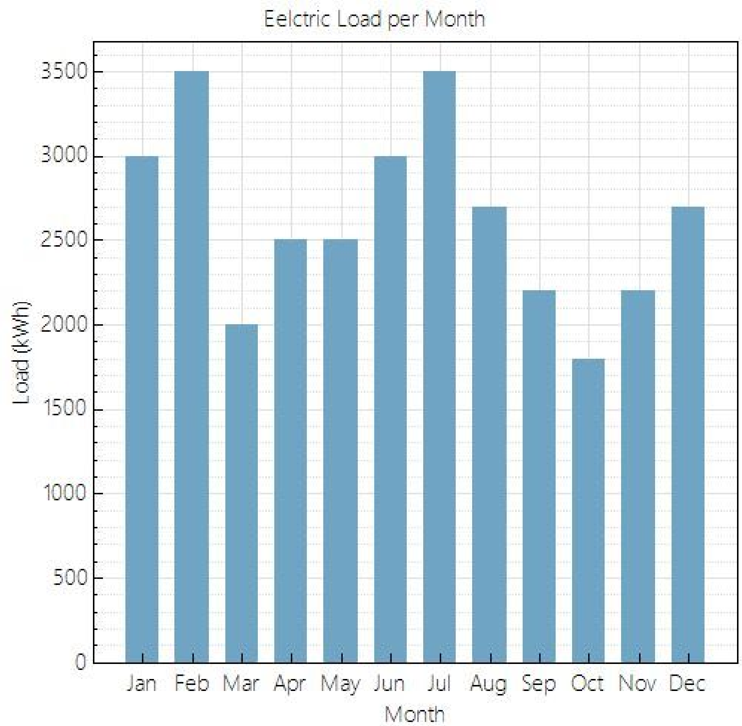


Figure 5: Education center electricity load per month w/o PV system

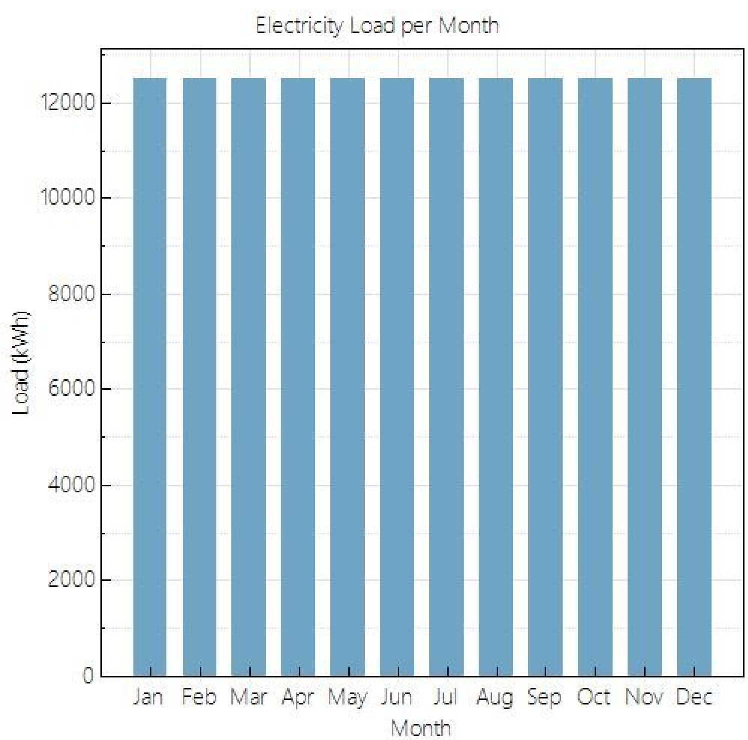


Figure 6: Sewage treatment plant electricity load per month w/o PV system

The system size for the sewage treatment plant was determined based on the load per month, but physical area, rather than electricity load was the restricting factor for the cabins and education center, so monthly load data was not useful for determining system size in these cases. For the sewage treatment plant, Helioscope and SAM simulations were used to determine array size, which was determined as 99.4 kWdc and an area of 556.3 square meters, or about half an acre. For the cabins and education center, Helioscope was used to determine the maximum energy generation for the given roof area, since Helioscope chooses ideal modules to optimize energy production for a given area. Based off of these simulations, the ideal cabin system was determined to have a nominal power of 5.7 kWdc with an area of 31.7 square meters, and the ideal education center system was determined to have a nominal power of 5.76 kWdc with an area of 17.5 square meters. To achieve these outputs, the panels at the sewage treatment plant were chosen to be Canadian Solar, CS6U 345M panels with maximum outputs of 345 W each. The chosen panels for the education center were Trina Solar, TSM-PD14 320 modules outputting a maximum of 320 W each. The chosen panels for the CCSP cabins were REC Solar REC280TP outputting a maximum of 280 W each. All panels were selected through Helioscope in order to maximize output for a given size. Both the education center and cabin rooftops held 20 of the selected modules, and the sewage treatment plant array contained 288 modules to reach nominal power. For each site, Helioscope optimization was also used to select inverters best suited to the location. At the cabins, Enphase M250 inverters were chosen due to the small load, multiple site nature of the CCSP cabins. For the education center, 1 SMA STP 24000TL, and at the sewage treatment plant, 4 SMA STP 24000TL inverters were selected due to the larger scale of the STP array. Based off of SAM simulations, the designs of the cabin and education center effectively offset energy consumption, and the design of the STP array effectively net zeroes the sewage treatment plant by producing 154000 kWh worth of electricity, while annual demand on site is 150000 kWh. Furthermore, each array is financially viable, with a positive NPV, though the payback period for the education center and cabins is high. Figures 7-12 illustrate the generation vs. demand for each array, and the overall SAM production and financial summary for each array.

Metric	Value
Annual energy (year 1)	6,580 kWh
Capacity factor (year 1)	13.4%
Energy yield (year 1)	1,175 kWh/kW
Performance ratio (year 1)	0.79
Levelized COE (nominal)	7.05 ¢/kWh
Levelized COE (real)	5.57 ¢/kWh
Electricity bill without system (year 1)	$1,692
Electricity bill with system (year 1)	$1,098
Net savings with system (year 1)	$594
Net present value	$130
Payback period	20.2 years
Discounted payback period	NaN
Net capital cost	$11,917
Equity	$0
Debt	$11,917

Figure 7: Cabins SAM summary

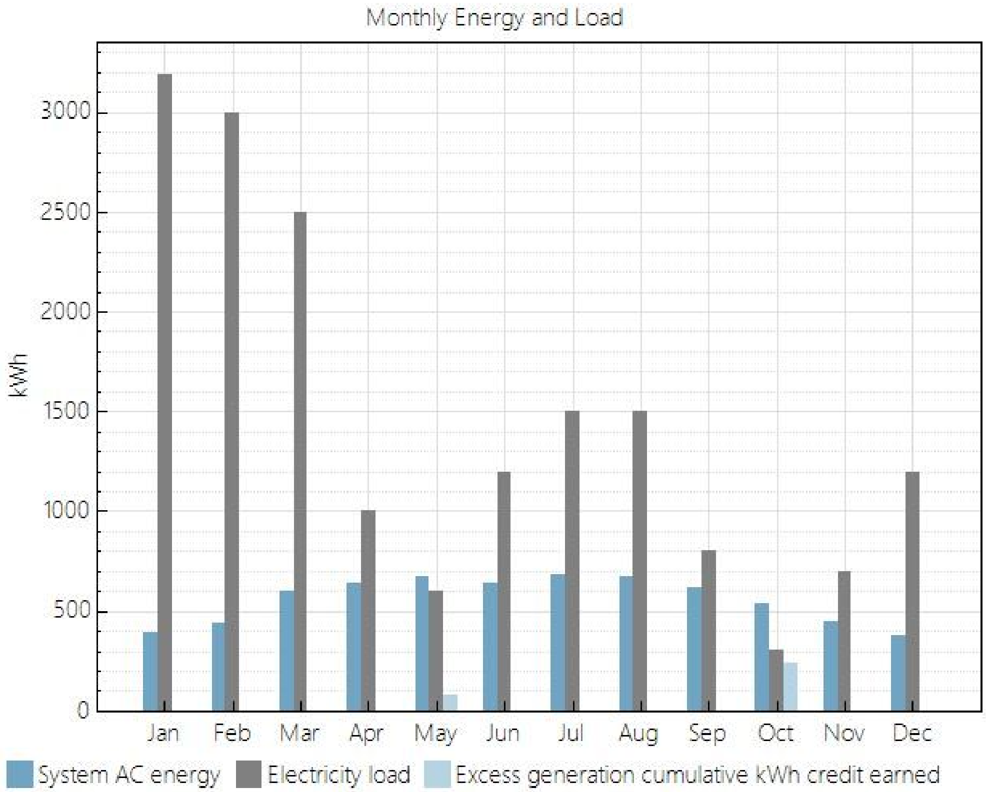


Figure 8: Cabins Gen vs. Load

Metric	Value
Annual energy (year 1)	3,337 kWh
Capacity factor (year 1)	13.2%
Energy yield (year 1)	1,158 kWh/kW
Performance ratio (year 1)	0.77
Levelized COE (nominal)	7.17 ¢/kWh
Levelized COE (real)	5.67 ¢/kWh
Electricity bill without system (year 1)	$4,040
Electricity bill with system (year 1)	$3,622
Net savings with system (year 1)	$418
Net present value	$978
Payback period	11.4 years
Discounted payback period	NaN
Net capital cost	$6,130
Equity	$0
Debt	$6,130

Figure 9: Education Center SAM summary

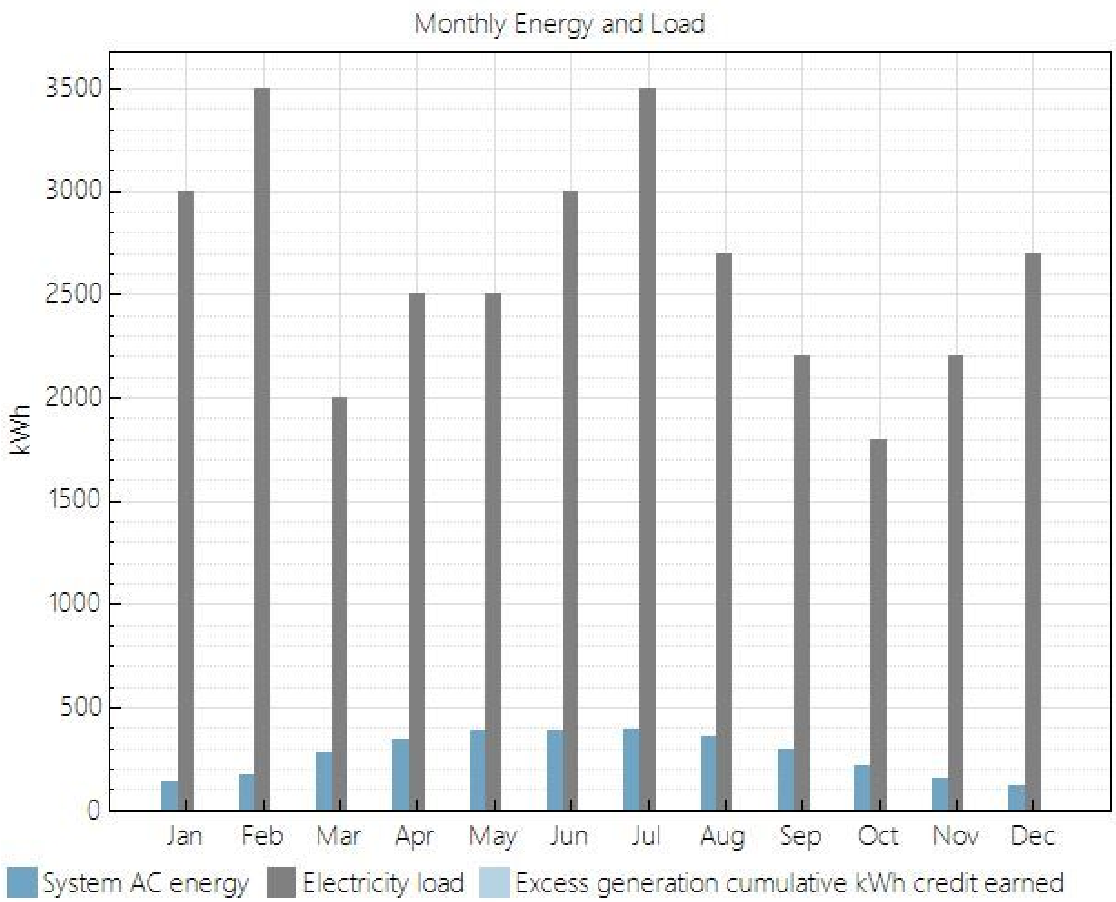


Figure 10: Education center Gen vs. Load

Metric	Value
Annual energy (year 1)	154,682 kWh
Capacity factor (year 1)	17.9%
Energy yield (year 1)	1,572 kWh/kW
Performance ratio (year 1)	0.80
Levelized COE (nominal)	4.08 ¢/kWh
Levelized COE (real)	3.23 ¢/kWh
Electricity bill without system (year 1)	$18,938
Electricity bill with system (year 1)	$700
Net savings with system (year 1)	$18,238
Net present value	$88,782
Payback period	6.5 years
Discounted payback period	9.5 years
Net capital cost	$209,283
Equity	$0
Debt	$209,283

Figure 11: Sewage treatment plant SAM summary

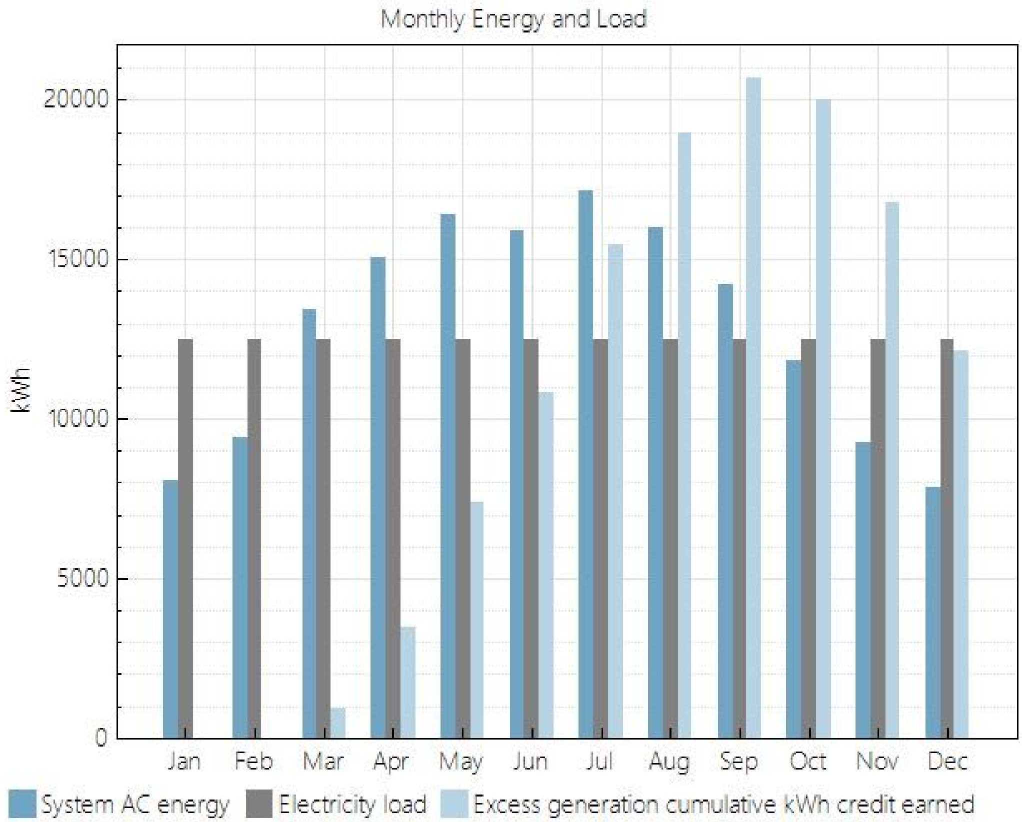


Figure 12: Sewage treatment plant Gen vs. Load

Unfortunately, shading information was not discoverable in our modeling. Though a Skelion model was developed, near and far shading renders did not accurately calculate the effect of foliage shading, or horizon shading. All attempted simulations failed. Based off of the foliage on site, the electricity generation at the cabins would be severely reduced without vegetation management. The education center would likely be minorly affected by near field shading, with vegetation management, and the sewage treatment plant array would require a setback of multiple meters in order to ensure near field shading from foliage is minimized. Figures 13-15 illustrate Skelion 3d models.

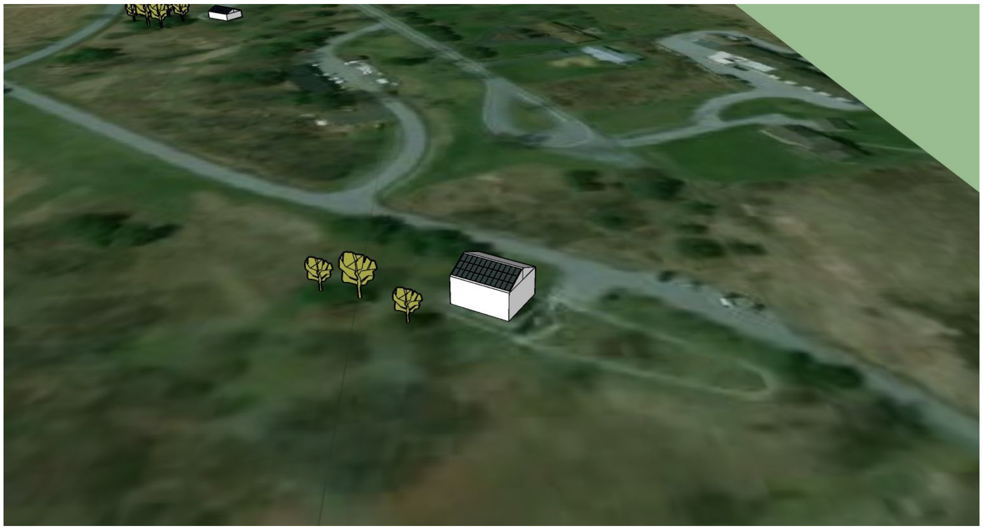


Figure 13: Skelion rendering of CCSP Ed Center

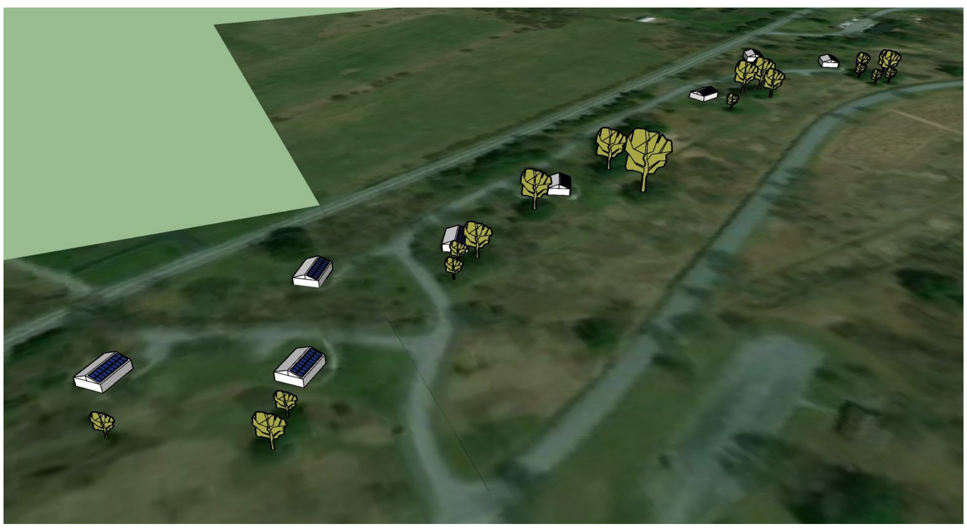


Figure 14: Skelion rendering of CCSP cabins

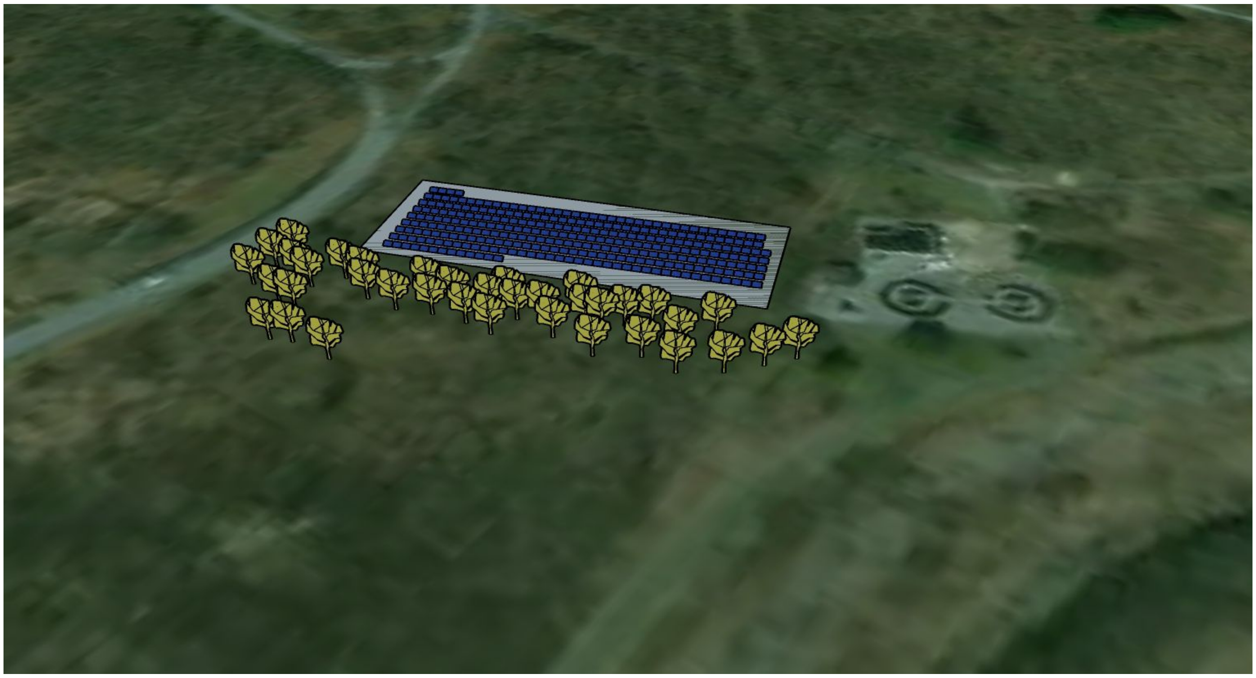


Figure 15: Skelion render of CCSP sewage treatment plant site

However, through Helioscope, weather shading losses for each array are estimated at roughly 7% based off on NREL weather data from 4 km away from our site. Furthermore, array shading effects for the STP array were accounted for in Helioscope, and row spacing of 2.4 meters was accounted for in order to minimize module shading effects.

Financial Options

The solar alternative energy credit (SAEC) is a financial incentive available to most sectors across Pennsylvania. The system must be operational before applying for a SAEC certification. Canoe Creek is a likely candidate to be certified because it adheres to all the necessary criteria. The incentives from this credit vary from year to year depending on market conditions but Canoe Creek would expect to be rewarded anywhere between $200 and $300 per cabin. Canoe Creek is also eligible to apply for the Solar Energy Loan Program. This program has a 25% cost share requirement and Canoe Creek must commit to matching investment of at least $1 for every $3 of program funds provided by the CFA. Clean Renewable Energy Bonds (CREBs) is a viable way to finance SECS in Canoe Creek from a federal incentive sector.

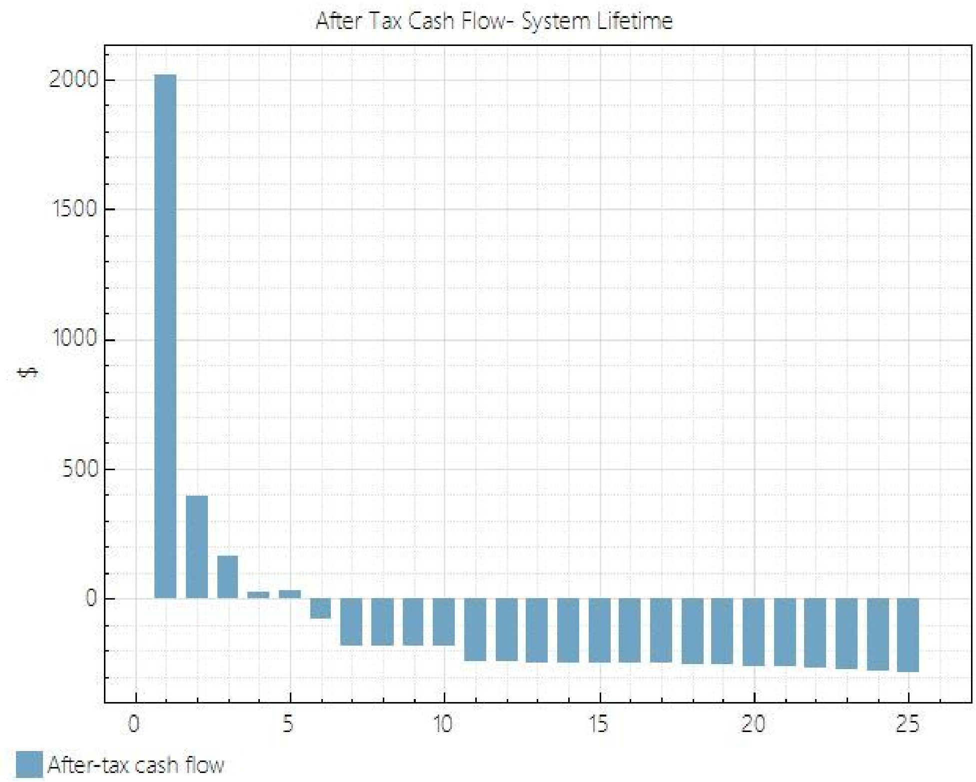


Figure 16: SAM Education Center cashflow

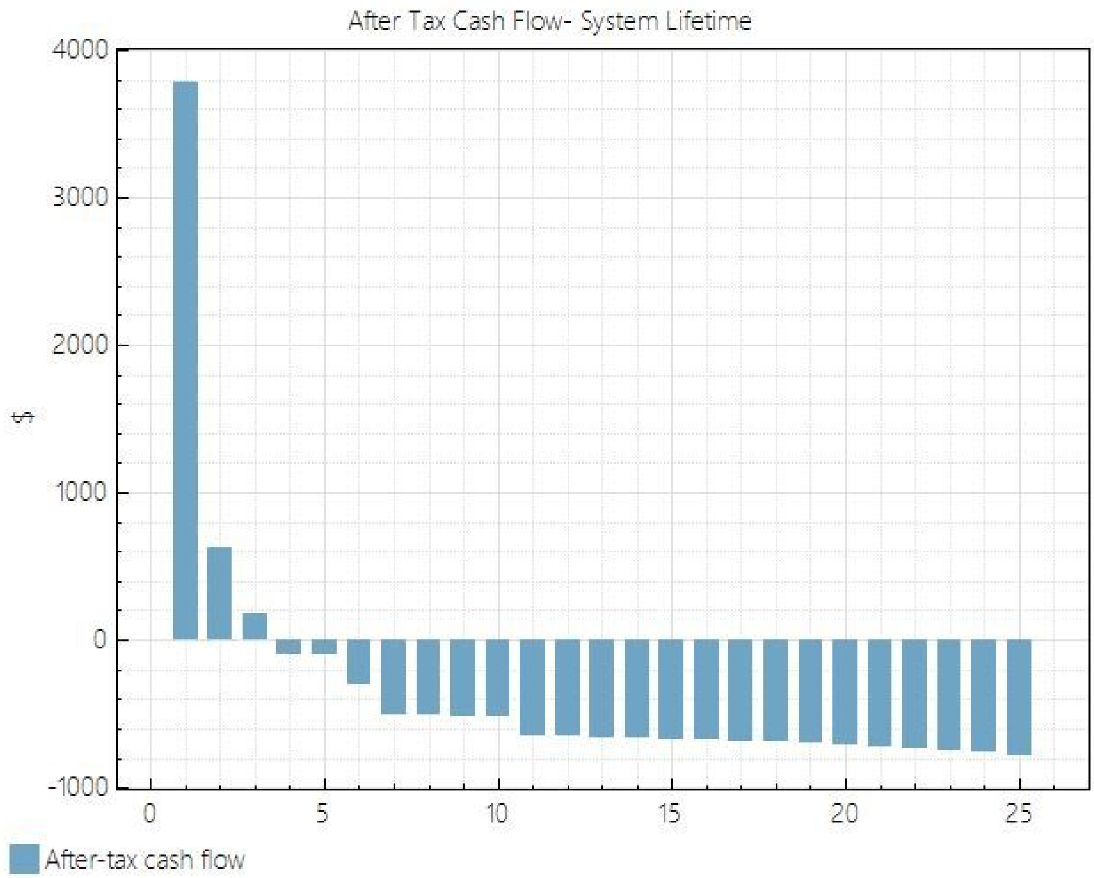


Figure 17: SAM Cabins Cashflow

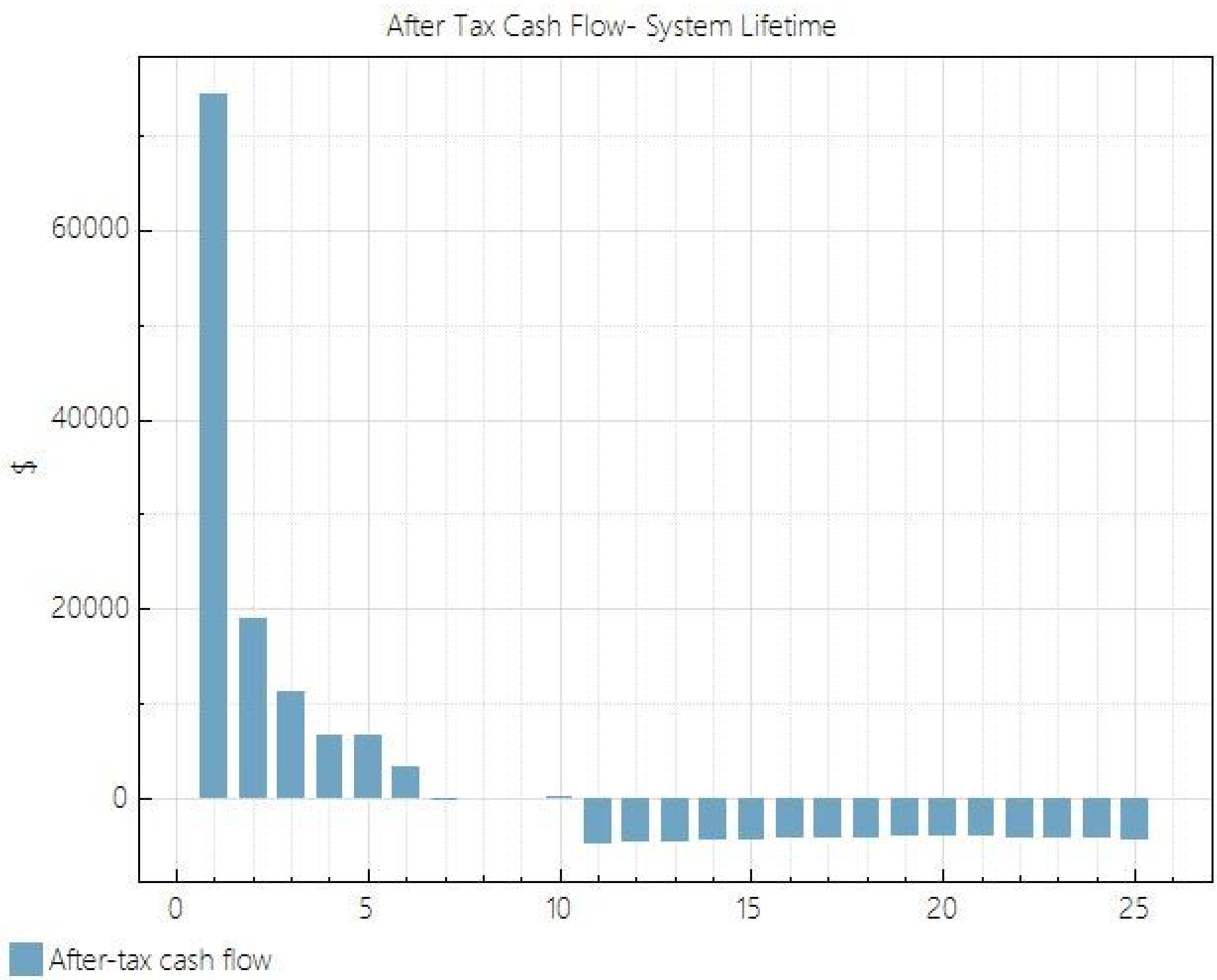
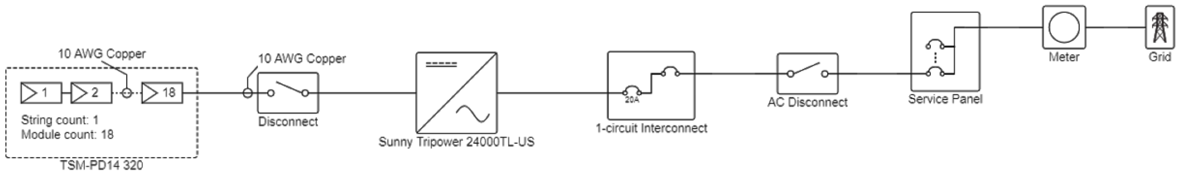


Figure 18: SAM Sewage Treatment Plant Cashflow

Conclusion

Based off of SAM simulations, Skelion designs, and financial research, PV systems are viable at CCSP. The sewage treatment plant energy demand can be completely offset by a large PV array with a footprint of half an acre, while the cabins and education center can only be offset considering that rooftop solar is the best option to limit landscape modification for those systems. The cost of an array for the sewage treatment plant would be $209,000 with a NPV of $88,000, and annual production of 154,000 kWh. An array for each cabin would cost $12,000 with an NPV of $130 and annual production of 6500 kWh. An array for the education center would cost $6,000 with a NPV of $1,000 and annual production of 3300 kWh. Though the systems are expensive, loans and grants could be provided through PA CREBs, and production credits like the SAEC are available. These

Appendix



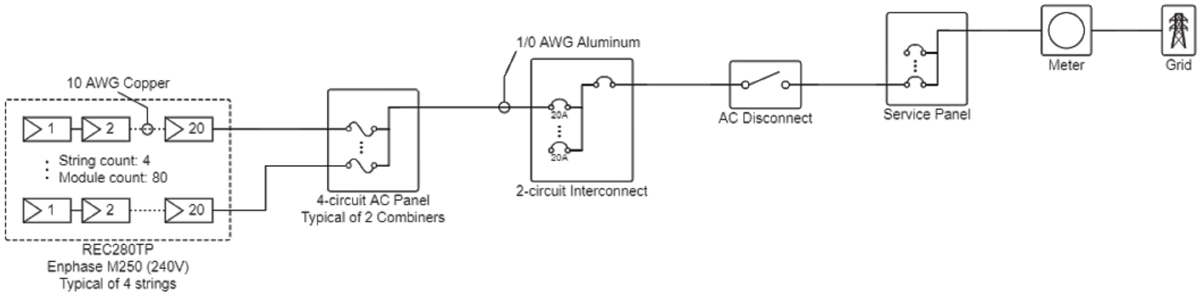
Module Specifications	
18x Trina Solar TSM-PD14 320	
STC Rating	320 W
Vmp	37.1 V
Imp	8.63 A
Voc	45.8 V
Isc	9.1 A

Inverter Specifications	
1x SMA Sunny Tripower 24000TL-US	
Max AC Power Rating	24.06 kW
Max Input Voltage	1,000 V

Wire Schedule		
Tier	Wire	Length
String	1x 10 AWG	<1m

A1: Helioscope Education Center Single Line Diagram

A2: Helioscope Ed Center Model



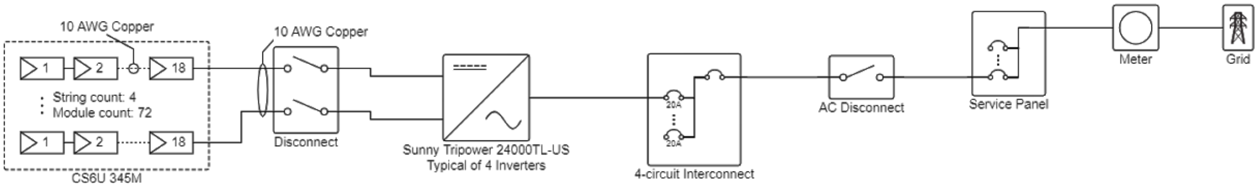
Module Specifications	
160x REC Solar REC280TP	
STC Rating	280 W
Vmp	31.9 V
Imp	8.78 A
Voc	39.2 V
Isc	9.44 A

Inverter Specifications	
160x Enphase M250 (240V)	
Max AC Power Rating	240 W
Max Input Voltage	48 V
Min AC Power Rating	0 W
Min Input Voltage	16 V

Wire Schedule		
Tier	Wire	Length
AC Run	2x 1/0 AWG	4448m

A3: Helioscope Cabins Single Line Diagram

A4: Helioscope STP Model

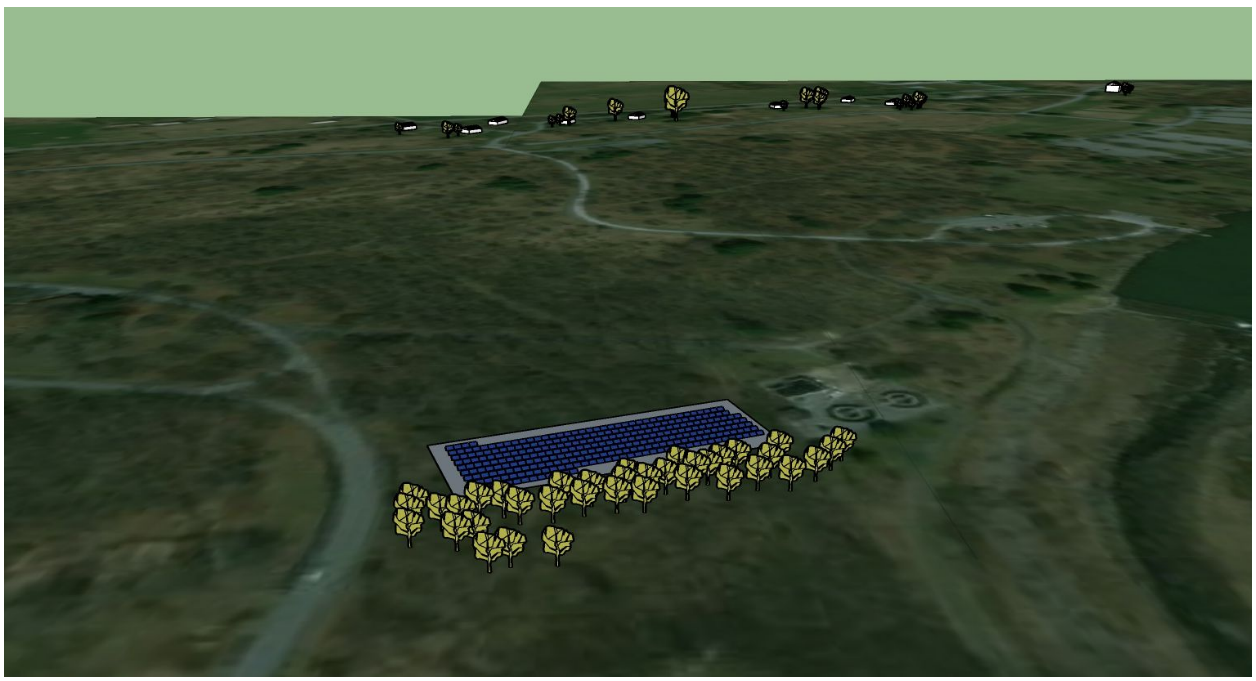


Module Specifications	
288x Canadian Solar CS6U 345M	
STC Rating	345 W
Vmp	38.1 V
Imp	9.06 A
Voc	46.4 V
Isc	9.56 A

Inverter Specifications	
4x SMA Sunny Tripower 24000TL-US	
Max AC Power Rating	24.06 kW
Max Input Voltage	1,000 V

Wire Schedule		
Tier	Wire	Length
String	16x 10 AWG	414m

A5: Helioscope STP Single Line Diagram



A6: Skelion Model of Full CCSP Site

Works Cited

Brownson, Jeffrey R. S. *Solar Energy Conversion Systems*. Academic Press, 2014.

Knier, Gil. “How Do Photovoltacis Work?” *NASA*, NASA, 6 Aug. 2008, science.nasa.gov/science-news/science-at-nasa/2002/solarcells.

“Save Electricity and Fuel.” *Department of Energy*, www.energy.gov/energysaver/save-electricity-and-fuel.

“Why Is Solar Energy Important?” *The Solar Company*, 16 Aug. 2010, www.thesolarco.com/why-is-solar-energy-important/.