Determining the Solar Energy Potential of McLaughlin Natural Reserve

ABT 212- Spring 2019
Path to Zero-net Energy: A hands-on approach

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1. Introduction

The Donald and Sylvia McLaughlin Natural Reserve protects 7,050 acres of habitat near Lower Lake, California. The land was entrusted to UC Davis and is predominately used by researchers conducting experiments on the rare flora and fauna found on the land around the facility. There are two main buildings which use electricity, the field station and the warehouse. The Field Station, which is fully occupied during the Spring and Summer months and utilized on occasion during the fall and winter, houses researchers, staff, and visitors while they are working and staying at the reserve. The Warehouse is occupied by both UC Davis and the mining company year round, but actual usage day-by-day is sporadic. The building is separated into an office space and a large shop area used for storage and facility operations. The large shop area is not climate controlled.

The reserve receives an extremely high annual electricity bill of the order of $33,000 for an energy use averaging 145,000 kWh/year as seen in Figure 1(Coffman A et al., 2018).The management of the reserve is interested in exploring renewable energy options, especially solar energy systems to power the facility. The aim is to reduce electricity cost and support UC Davis' carbon-neutrality initiative to the maximum extent possible.

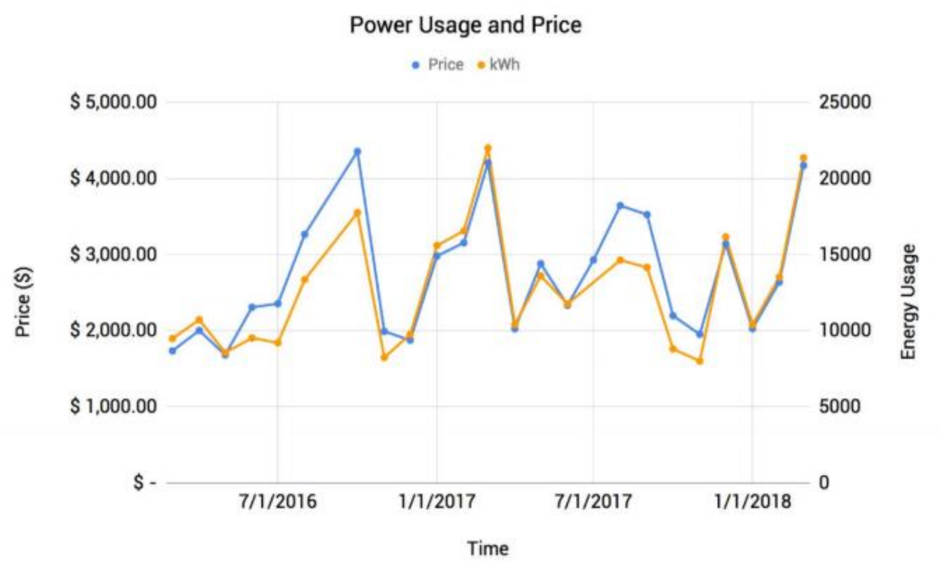


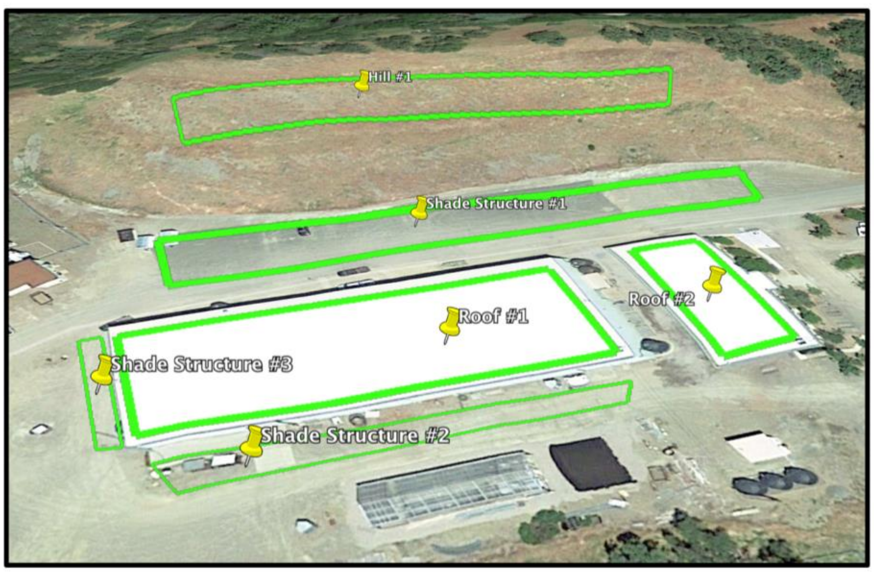
Figure 1: McLaughlin Reserve Energy Usage and Electricity Cost

The director's vision includes determining the full solar potential of the facility by utilizing all the suitable surfaces for PV. As seen in Figure 2, this includes the roofs of the warehouse and field station, marked Roof #1 and Roof #2 respectively, the south-facing hillside, marked Hill #1 and the construction of parking structures marked Shade Structure #1, Shade Structure #2 and Shade Structure #3. Each of these areas were to be analyzed for various factors and design recommendations were to be made based on the objective functions defined below.

- Energy Usage Cost- Minimized
- Solar Energy Potential- Maximized
- Carbon Neutrality- Maximized
- Capital Investment- Minimized

The scope of the project also extended to

- Determine maximum solar potential with the area available
- Provide funding suggestions



Location	Area (ft^2)
Hill #1	10,805
Shade Structure #1	15,645
Shade Structure #2	3,400
Shade Structure #3	880
Roof #1	19,200
Roof #2	4,230

Image Landsat / Copernicus
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Figure 2: Potential Photovoltaic Infrastructure Locations

2. Methodology

An ASHRAE Level 1 Energy Audit was conducted prior to the project which was thoroughly studied. The energy loads and patterns of energy usage through the year were summarized and the load requirement to be met was understood. A site visit to the facility helped in the understanding about the surrounding topology, shadows and defined the scope of the project. The designs were then completed using the following sequence of steps.

2.1 Assumptions and Constraints

Major assumptions made in this analysis were associated with the modeling software utilized. It was assumed the data used to make the calculations in PVsyst and Homer Pro were calibrated and the associated error in the modeling was minimized. Below is a list of the major assumptions associated with the modeling.

- Mono Crystal Si Panels utilized and modeled
    - Most efficient for a negligible increase in cost over Poly Crystal Si panels
- Horizon angle approximately 3 degrees
    - the sun rises over a hill in the morning
- Generic wiring, inverters and solar panels were used in the modeling
    - Cost and losses were generalized over available equipment in the market
- Installation and transportation cost assumed in model pricing
    - Approximated costs from dealer quotes
- Panel cleaning not included in cost and efficiency analysis
- Efficiency variance with temperature not included in the model
- Losses in equipment are considered negligible

2.2 Spatial Analysis

To determine the surface area available for the installment of PV, a spatial analysis was conducted using geographical information systems (GIS) and Google Earth. The areas of the roof structures, the hillside, and feasible areas for parking structures were measured using satellite imagery from Google Earth as seen in Figure 2. The monthly direct solar irradiance was calculated in GIS

(ArcMap 10.7) using elevation profiles of the region (DEM file) and the solar irradiance tool. To enhance the accuracy of the GIS solar irradiance analysis, the daily direct solar irradiance from the closest weather station, Knoxville Creek California Weather Station, was obtained and used calibrate the solar irradiance tool. The hillshade and slope angle of the hillside were also determined using GIS. The average daily direct solar irradiance, hill shade, and slope angle values were then used for modeling the PV system.

2.3 System Design

2.3.1 System modeling using PVsyst

Irradiation and weather data was obtained from PVsyst using the location (38°52’26’’N 122°25’54’’W) of the reserve. This data was then validated with GIS using global horizontal irradiation data from Knoxville Creek California Weather Station. The available area of all the potential infrastructure locations were then listed as shown in Table and their specific locations and heights with respect to the ground were included. It was also determined that, for the given location and application, a 30 degree tilt of the panels towards the south increased the global horizontal irradiance by 15% as seen in Figure 3.

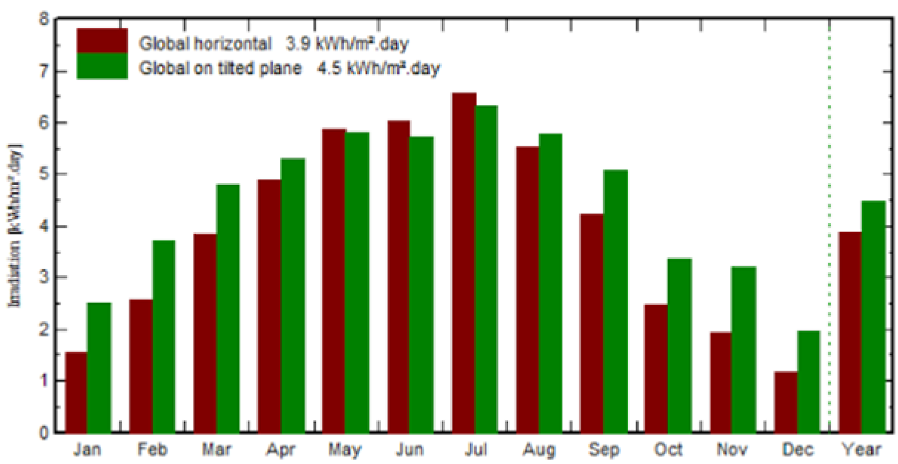


Figure 3: Graph showing increase in irradiance for 30° south tilt of panels

2.3.2 HomerPro Analysis

Using The Reserve's monthly electricity bill over the past 11 months, the average daily load and the average cost per kW was determined. Using these values and the most economical PV panel, HomerPro was used to model the system for maximum production and the required production of each potential infrastructure location mentioned above. The Homer Pro model provided the levelized cost of energy (LCOE) for each system as well as the initial capital investment.

2.4 Lifecycle, Cost, and Carbon Analysis

In order to determine our life cycle analysis, we decided to start with the origin of the product. We follow ISO 14040:2006 standard. We divide the product chain into several large blocks, namely raw material acquisition and purification, solar panel manufacturing, frame and inverter manufacturing, board assembly, transportation, and use phase. Because of the budget and time cost of our projects, we are not able to use the most specialized database (such as Gabi or Simapro) to analyze each material and each process that involved in this process. Therefore, we summarize it from many pieces of literature and based on the solar panels we use. The specifications are introduced to calculate and ultimately the carbon cost of the life cycle of our solar system.

3. Results & Discussion

3.1 Solar Potential

The preliminary analysis revealed The Reserve will require either storage or net-metering to meet demand as shown in Figure 4. The consumption of energy exceeds the potential of Roof 1 when modeled to meet the demand of 145,000 kWh annually. The client expressed no interest in batteries or storage; therefore, a net metering system is the best option. Net-metering will also be required for a Purchase Power Agreement (PPA), which was previously suggested by the Coffman et al. (2018) and interest in a PPA was expressed by the client.

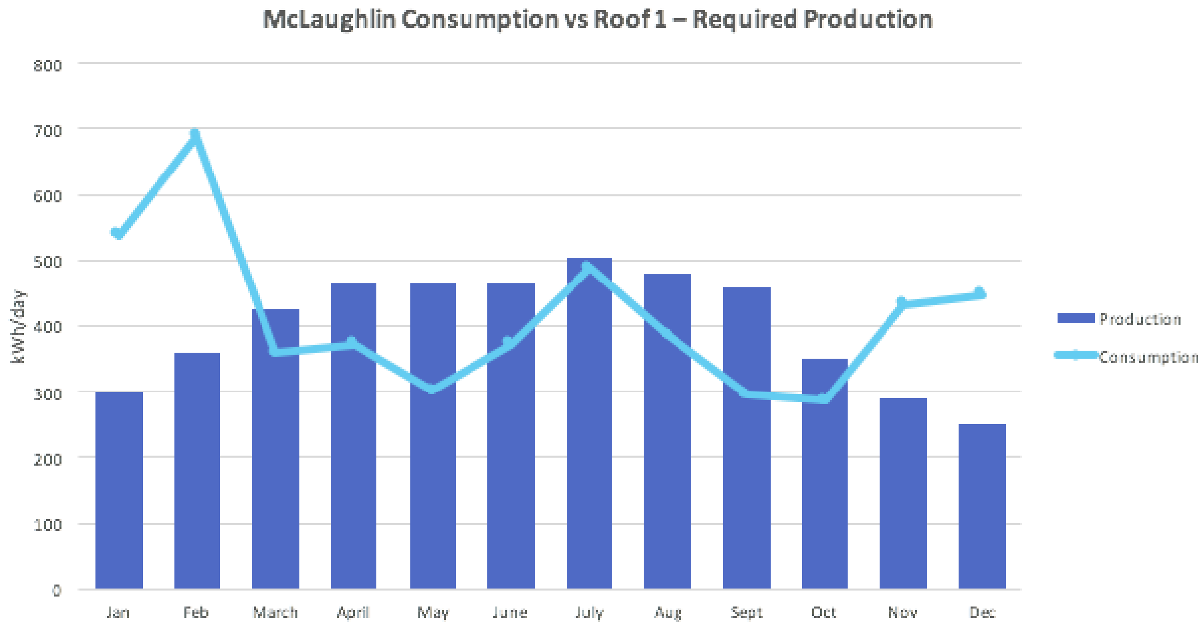


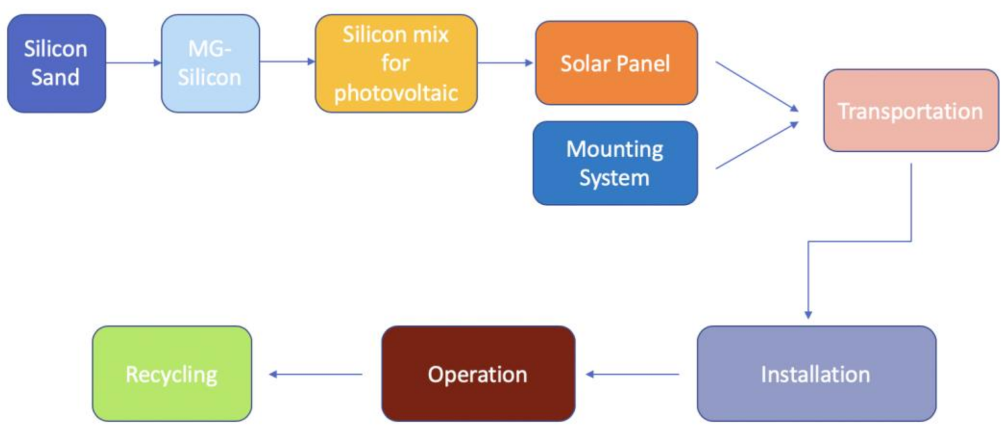
Figure 4. Total energy consumed by the reserve annually compared to the modeled production of the Roof 1 PV system to meet demand.

Table 1. PVsyst and HomerPro model results for each of the Potential PV Infrastructure Locations

	Potential	Area (ft^2)	Panel Tilt Azimuth (˚)	Energy (kWh)	LCOE ($/kWh)	Investment ($)
Roof 1	Max	19,200	30,0	438,920	0.07	$724,281.00
	Required	6,340		145,240	0.06	$241,226.00
Roof 2	Max	4,230	30,0	96,498	0.064	$160,016.00
	Required	Not met				
Hillside	Max	10,805	38, -60	221,224	0.0649	$377,148.00
	Required	7,082		145,000	0.0648	$251,422.00
Shade Structure 1	Max	15,645	30,0	357,590	0.0649	$590,133.00
	Required	6,340		145,240	0.0648	$240,023.00
Total	Max	49,880	-	1,114,232	0.068	$1.85 million

Solar potential of the potential PV infrastructure location is summarized in Table 1. Shade structures two and three were not included because it was determined the surface area would not be sufficient and the cost associated with energy production is not feasible. Roof 2 at its maximum potential will not provide sufficient energy to meet the demands of The Reserve. In comparing the initial capital investment between each option, Roof 1 max potential is the highest price, however, it provides the highest energy output. The cost associated with the capital investment for the Hillside was based on only the installation of the panels and a price of $4,000 was added to account for the pricing difference for ground mounted panels. The LCOE of each system came out to generally the same price around $0.06 and $0.07 per kWh, so it was not used in determining the most cost-effective option. If the client were to install each of the options listed in Table 1, the total capital investment will be 1.85 million dollars with an overall production of 1,114,232 kWh.

3.2 Carbon



For the raw materials extraction/purification and the manufacturing of solar panels, the literature shows a big gap between current (published within 3 year) and previous studies (2015 or before). In fact, there is a rapid technology innovation in the past five years, and the energy consumption of extracting and producing a 1kW monocrystalline silicon solar panel has dropped from an average 10000 MJ/m^2 to 1000MJ/m^2 (Wu et al., 2017). There is also a rapid revolution in the efficiency of solar panels. According to the previous literature, between 2012-2014, for monocrystalline silicon solar panel, the average efficiency is between 14.0%-14.2% (NREL, 2012; Gerbinet et al., 2014), but the efficiency of the current model of monocrystalline silicon solar panels is about 19-20% (SunPower, 2018), which has a significant improvement over the system five years ago. Therefore, most of the literature of solar panels is outdated.

Therefore, our research reduced the scope of literature and only use paper published after 2017 to increase the accuracy of carbon dioxide and energy projections. Raw materials account for the highest proportion of energy in this system, and we estimate a total of approximately 4,219 MJ/kW panel, as California's combined power emissions are approximately 427 gram/kWh electricity (ARB, 2018), which is more than the national average of kWh of electricity produced per kWh of electricity. The emissions are low, so we calculate the raw materials to produce about 26 gram/kWh of carbon dioxide (Wu et al., 2017). Similarly, the energy consumption for manufacturing and assembly is about 5907 MJ/kW, and the carbon dioxide intensity is about 36 gram. /kWh. At the same time, because in our system, about 7kW of solar panels are equipped with an inverter, we estimate the energy consumption and carbon dioxide intensity of the inverter are 400 MJ/kWh and 2.11 gram/kWh respectively. Transportation per kW of solar power The plate also requires approximately 59 MJ and produces 1.07 gram of carbon dioxide. Here, we also assume that most of the boards are assembled in China and shipped by ocean freighters. After being shipped to the retailer, the distance to the consumer is no more than 50 miles (assuming each dealer is responsible). A radius of 50 miles). The user's stage of use of carbon dioxide is extremely low, which is largely negligible, mainly to clean up the carbon dioxide consumed, estimated to be about 1.0 gram/kWh, which is 400 times lower than the average value of California's electricity carbon dioxide. In the end, we calculated that the carbon intensity of our designed solar system is about 68 gram/kWh, which is basically in line with other studies. Of course, our research also has some shortcomings, because we have neglected some other small parts, including wires, including screws, fixtures, etc. We can only roughly estimate these originals to produce about 3g/kWh of carbon dioxide based on other studies.

3.3 Power Purchase Agreement (PPA)

SunPower in California and was contacted and asked to quote a PV system for Roof 1 of the McLaughlin Reserve. The project plans were discussed in detail and maps of the reserve were provided, so they could identify where solar panels can be installed. According to SunPower's forecast, the PV system that Mclaughlin Reserve can build to meet its current demand is 84.2 kW. In their analysis, the distance between the panels and HVAC system located on the roof was considered. because they consider that solar panels and HVAC systems need to maintain a certain distance. At the same time, they made an estimate electricity usage based on the electricity bill for the past three years (2016-2019) and generated an investment plan to fulfill the basic solar demand.

The maximum load solar system requires ground mountings and parking shades, which increase the system cost, the agent of SunPower didn't recommend (e.g. each individual mounting system costs about $4,000). The current rooftop system they design is about 124,122 kWh/yr. and the price proposed is about 16 cents a kilowatt, with an annual increase of about 5 percent, which is 30 cents lower than PG&E. Electricity prices. There is also a prepaid option which UC Davis would only need to pay for $172,295 upfront (which is 15% off compared to the system purchase price) and then pay the rest maintenance fee at year 15 and 25 for inverter replacement. The current intention is to sign a 25-year contract with UC Davis, after 25 years, UC Davis take the ownership of the system.

Our calculations show that in the next 30 years, if the PPA system is used, Mclaughlin Reserve will save about $30,460.48 just at the first year, and the electricity bill savings for 30 years will be as high as $1,525,447. The total cost of this PPA for 30 years is only $208,256, which is a very reliable price forecast. They would still need to pay the electric bill from PG&E, which is about $2300 per year. But 90% of the bills are eliminated through this system.

Using literature (Kollins, 2010) and SunPower's results, we confirmed our model results. The discrepancy in the values can be attributed to the assumptions and constraints in our analysis as well as the different proposed systems. SunPower recommend an 84. 2 kW where the PVsyst and HomerPro models suggests an 87 kW system, this is a small difference, however. Summarized in Table XX are the investment summaries from SunPower and the models. According to literature (Kollins, 2010; Horváth &Szabó, 2018) utility scale PPA systems are currently running for about $0.03 / kWh and for smaller systems $ 0.10 / kWh. The results from the analysis agree with this information. The full report from SunPower is found in the appendices.

Table 2. Comparison of PV system investments for SunPower and project models

	Initial Capital Cost*	LCOE	PPA Pricing**
PVsyst & Homer	$241,226.00	$0.06	$ 0.10 / kWh
SunPower	$208,256.00	$0.14	$ 0.16 / kWh

*Based on 12.2 kW system from SunPower and 87 kW system from models

**Pricing from the models was determined through literature and advice from David Phillips

4. Recommendations & Conclusions

SunPower and the project models agree Roof 1 is the best option for McLaughlin Reserve based on meeting each of the objective functions as followed:

1. Energy Usage Cost- Minimized

- PPA Pricing of $ 0.16 / kWh for a Roof system that meets The Reserve's current demand

2. Solar Energy Potential- Maximized

- Maximum energy production from Roof 1 is 438,920 kWh projected from models
- SunPower system to only meet demand 124,122 kWh
- Model system to only meet demand 145,240 kWh

3. Carbon Neutrality- Maximized

- For meeting demand with Roof 1, 686.6 kg of carbon dioxide equivalent in 30 years will be saved. For the system which maximizes the energy output, it can save about 11,984.6 kg of carbon dioxide in 30 years.

4. Capital Investment- Minimized

- Estimated cost for SunPower system is $172,295 total upfront payment with UC Davis discount. The total initial payment is $208,256.
- The model projects an initial capital investment of $241,226

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